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Efficiency of pumping and piping layout, January 1963

R. G. Warnock

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CIVIL ENGINEERING DEPARTMENT
FRITZ ENGINEERING LABORATORY
HYDRAULICS DIVISION

PROJECT REPORT NO. 37

EFFICIENCY OF PUMPING AND PIPING LAYOUT

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EFFICIENCY

OF

PUMPING AND PIPING LAYOUT

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NATIONAL BULK CARRIERS, INC.
360 Lexington Avenue
New York 17, N. Y.

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PREFACE

A contract between Lehigh University, Institute of Research, Fritz Engineering Laboratory, Hydraulics Division, and National Bulk Carriers, Inc. provided for experimental and analytical studies on efficiency of pumping and piping layout.

The sponsor is planning to build a very large 6-pump boom dredge. One method of pumping to be considered is to combine all pump discharges into a single discharge line, while an alternate way is to have separate discharge lines. The question of interest here is whether the efficiencies and discharges of pumps are seriously reduced from those obtained with separate discharges, if the pumps are discharging into a common line and the operation conditions for the pumps are not the same. The operating conditions of interest are differences in speed of the pumps and differences in liquid that is pumped, for example, water and water-solids mixtures.

In order to study the importance of these differences an experimental investigation was made using two pumps. The first phase was a study of the effect of a difference in speed of the two pumps. The second phase was a test of the two pumps with one pumping water and the other pumping a water-solids mixture. Losses in the wye connection were also measured.

The main body of the report is devoted to the description of test facility, experimental results, and conclusions.

The project was under general direction of Professor John B. Herbich, Chairman of the Hydraulics Division. Professor R. G. Warnock supervised the complete study and performed most of the experiments with the assistance of Mr. V. R. Mariani, Research Assistant. Mr. E. G. Dittbrenner installed the equipment and assisted in the tests. Manuscript preparation was done by Miss J. E. Fritz. Professor W. J. Eney is the Head of the Civil Engineering Department and Fritz Engineering Laboratory; Professor L. S. Beedle is the Director of Fritz Engineering Laboratory.

ABSTRACT

This investigatinn was concerned with the efficiency of the piping layout for two dredge pumps. Operation of the pumps in parallel at different speeds and with different fluids was compared to operation of the pumps separately.

Results showed only small effects on discharge and efficiency for the conditions tested.

Head losses in a wye were also measured. The wye was found to be highly inefficient for a high discharge in one leg and a low discharge in the other leg.

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LIST OF SYMBOLS

BHP = Brake horse power

C_L = Coefficient of loss

D = Diameter

e = Efficiency

f = Friction factor

g = Gravitational acceleration

H,h = Head

h_f = Frictional head loss

H_L = Head loss

L = Length

N = Impeller speed (rpm)

N_s = Specific speed

Q = Discharge

V = Velocity

WHP = Water horse power

γ = Fluid density

Subscripts m and p refer to model and prototype.

Subscripts 1 and 2 refer to pump No. 1 and pump No. 2.

Subscripts 1, 2, 3, and 4 refer to pressure taps on wye.

PRELIMINARY REPORT ON

EFFICIENCY OF PUMPING AND PIPING LAYOUT

I. INTRODUCTION

While the hydraulic efficiency of a pumping system is an important consideration in its design, other limiting factors must often be considered as well. In the case of a boom dredge the weight of the boom must not be excessive as this would increase the draft of the dredge and thus reduce its operating capabilities as well as introduce more severe structural requirements for the boom. It is in this connection that a question has arisen regarding the problem considered herein.

The purpose of this investigation was to determine experimentally the characteristics of a combined pumping system composed of two pumps in order that it might be compared to the two pumps operating separately. Two operating conditions of particular interest are: (1) the two pumps operating at slightly different speeds and (2) one pump pumping water and the other pump pumping a clay-cilt-water slurry.

The experimental program began with each pump being operated singly at three different speeds and then the two pumps being operated together with the speed of one pump being slightly varied. Head loss measurements were also made in the wye which joined the discharge pipes of the two pumps. These tests were followed by a test of the pumps operating together with one pumping water and the other pumping water-solids mixture. This test was of necessity limited to a single run of short duration because of the impossibility of recirculating the pumped fluid.

II. MODEL-PROTOTYPE RELATIONS

The results presented here are based upon model pump tests. In this section the relationships used to predict prototype performance from model results is discussed with appropriate comments.

True similarity between model and prototype would require model surfaces with accurately scaled-down roughness and equality of Reynolds' numbers between model and prototype. Since this is seldom practical, model pump tests are usually run at prototype heads and velocities to more closely approach the prototype Reynolds' number with corrections being made to the results as deemed advisable. Also, the model surfaces are made as smooth as possible. Such was the case in these tests; the heads in the model tests are assumed to be equal to those which would be obtained from the prototype pump handling the same fluid.

To obtain a relationship between model and prototype discharge, it is only necessary to consider that

$$Q \propto V L^2$$

Since V, the velocity, is the same in model and prototype

$$\frac{Q_p}{Q_m} = \left(\frac{L_p}{L_m}\right)^2$$

or for these tests in which the length ratio is 8,

$$Q_p = 64\ Q_m \qquad (1)$$

In order to find the prototype-model speed relation it is convenient to use the equality of specific speeds in the model and the prototype,

$$(N_s)_m = (N_s)_p$$

Since $N_s = \frac{N\sqrt{Q}}{H^{3/4}}$ and since H is the same in the model and the prototype, then

$$N_m\sqrt{Q_m} = N_p\sqrt{Q_p}$$

or

$$N_p = \frac{L_m}{L_p} N_m$$

In this case then

$$N_p = 1/8\ N_m \qquad (2)$$

The next characteristic to be considered is that of efficiency. The assumption made here which is often used is that prototype efficiencies will be equal to those obtained in the model when they are pumping the same fluid. This is a conservative assumption since it has been found that prototype efficiencies are usually somewhat higher than those in the model due in part, presumably, to the lower Reynolds' number and higher relative roughness in the model.

In order to relate the brake horespower of the model to that of the prototype, it is recalled that the water horsepower is equal to the brake horsepower times the efficiency.

$$WHP = \frac{\gamma QH}{550} = e\ (BHP)$$

Since the efficiencies and heads are assumed equal in the model and prototype, the resulting relation is

$$BHP_p = \frac{Q_p}{Q_m}\ BHP_m$$

or for these tests (3)

$$BHP_p = 64\ BHP_m$$

In summary, for a 1:8 size ratio and identical fluids the model-prototype relations are

$$Q_p = 64\ Q_m \quad (1)$$

$$N_p = 1/8\ N_m \quad (2)$$

$$BHP_p = 64\ BHP_m \quad (3)$$

$$e_p = e_m \quad (4)$$

$$H_p = H_m \quad (5)$$

III. EXPERIMENTAL STUDIES

A. Equipment

The test facility consists of two large tanks , two centrifugal pumps operated by two direct-current motors, and piping to recirculate the fluid with a wye to join the two discharge lines. Figure I shows the layout of the system. A description of the equipment follows.

1. Pumps - The pumps are 1 to 8 scale models of a centrifugal dredge pump being used on S. S. Zulia. One pump is composed of an impeller and volute cast in bronze, while the other one has a plexiglas impeller and volute. The impeller used is designated as Trial Design 7. It has a 45° entrance angle, a 22° 30' exit angle and its profile is an involute curve. A further description of it may be found in Reference (1). The pump shafts are of stainless steel and are supported by antifriction type bearings (ball bearings to absorb the radial and thrust loads of the pump.) The staffing box seal is of mechanical type made by Garlock Packing Company (MECHANI-PAK SEAL, type BB 21-A, with style B stationary seat).

2. Motors - The motors are 40 hp Direct Current LIFELINE H, frame 405-A motors manufactured by Westinghouse Electric Corporation, Buffalo, New York. These motors are especially designed to provide

a wide speed range and accurate regulation of the speed. The motors were calibrated prior to shipment to the laboratory. This was required for determination of the power input.

3. Flow Meters and Dynalog Recorders - The flows were measured by means of Magnetic Flow Meters manufactured by the Foxboro Company, Foxboro, Massachusetts. The operation of this meter is based on Faraday's law. A magnetic field is set up across the pipe by an electro magnet. The water moving through the magnetic field generates a voltage which is proportional to the velocity of flow. The voltage is picked up by two electrodes in the wall of the pipe, measured, and recorded in units of flow by an electronic, self-balancing Dynalog Recorder. The Dynalog Recorder converts the electrical variations of voltage into mechanical movements which are recorded on a revolving chart by means of a pen attached to the recorder by a link arrangement. An accuracy of one per cent in flow measurement for the meter is claimed by the manufacturer.

4. Piping - The piping system, starting on the suction side consists of a 6-inch "drag arm" section of pipe inside the tank, which is followed by a 4 1/2-inch suctionline to the pump. The discharge pipe is 4 inches in diameter followed by a flow meter with 4-inch pipe from the flow meter to the wye. This arrangement is the same for both pumps. A sketch of the wye is shown in Figure 2. After the wye 6-inch pipe returns the combined flow to the tanks with provision made to direct the fluid to a third tank.

5. Other Measuring Equipment - Discharge and suction heads were measured by means of manometers. Two 100-inch mercury-water manometers in series were used with each pump to measure discharge

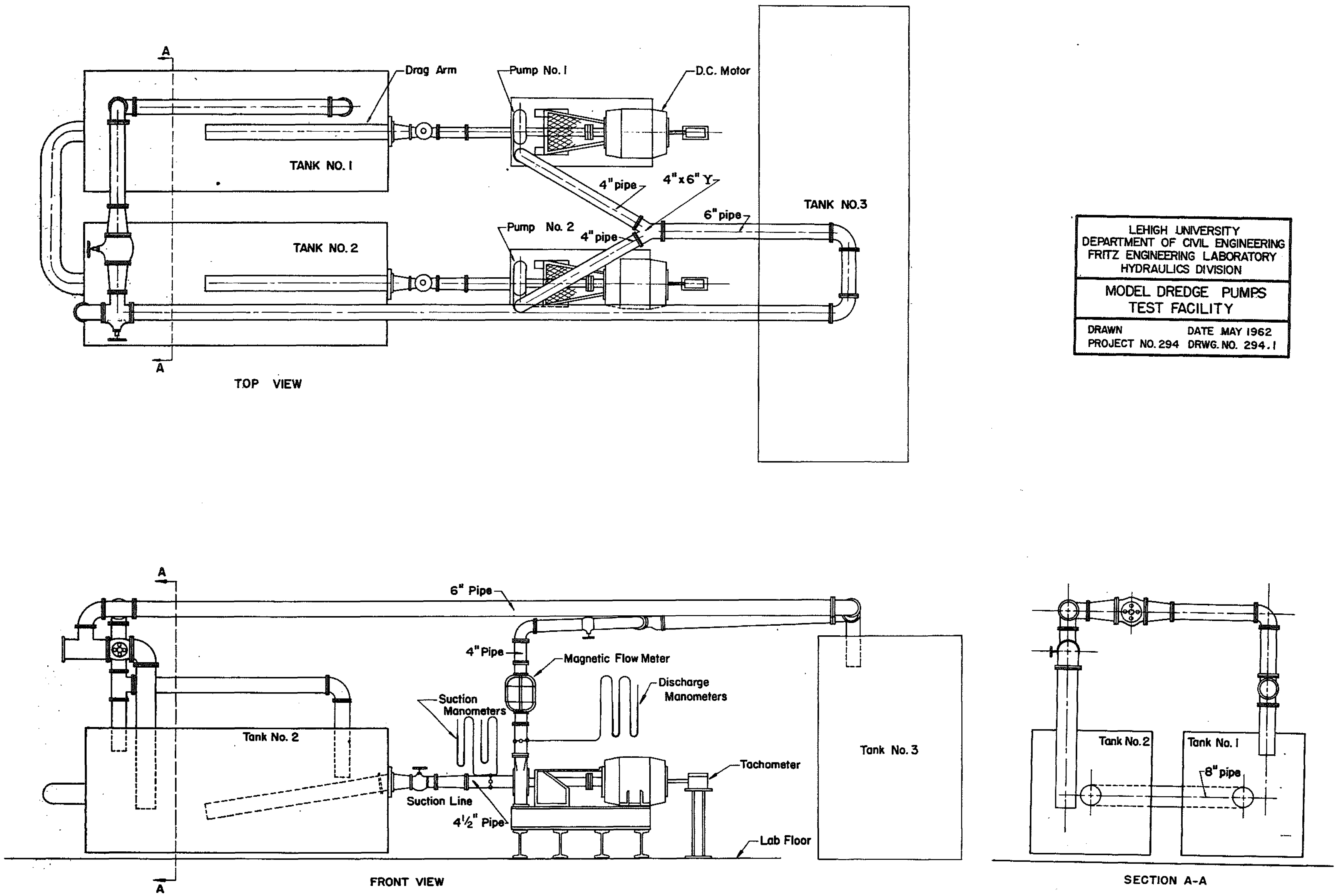


Fig. 1 Test Facility

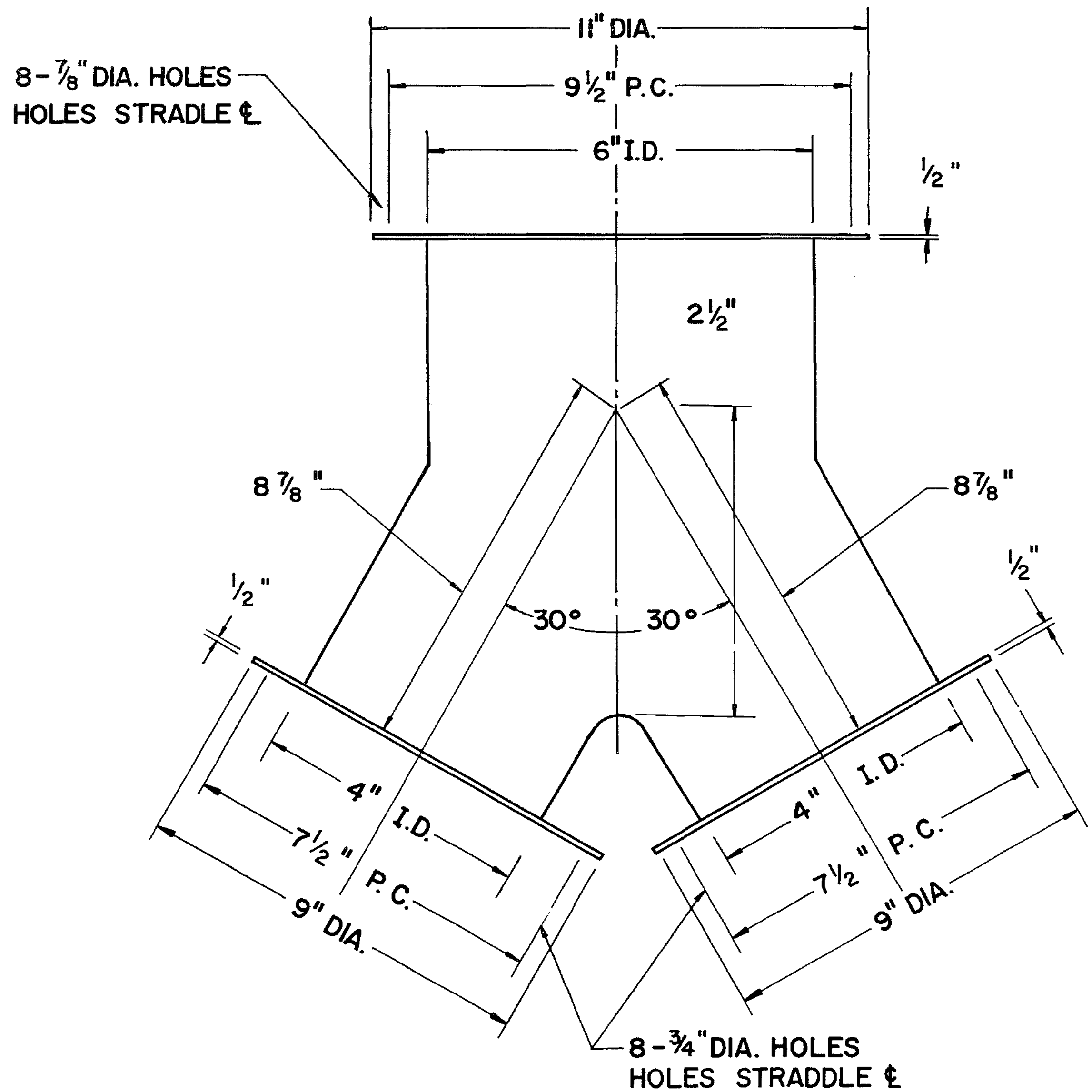


FIG. 2 DETAILS OF 4" x 6" WYE

heads. The suction presssures were measured at low flows with a carbon tetrachloride-water manometer and at higher flows with an air-mercury manometer. Head losses in the wye were measured with a differential manometer with measuring fluid of specific gravity of 2.95.

Speeds were measured approximately by tachometer-generator sets mounted on the shafts to the motors. Since the speed variation was of primary interest in the tests, a recently calibrated hand tachometer manufactured by Hasler was used to set the speed accurately.

The voltages, amperages, and approximate speeds were read on the control panels supplied by the Euclid Electric Company, Madison, Ohio.

B. Procedure

In single pump tests the following procedure was followed:

1. The voltage was set to 240 volts.
2. The motor was started and brought to the approximate test speed as indicated by the electric tachometer.
3. The voltage was readjusted if necessary.
4. Using the hand tachometer the motor was adjusted to less than +2 rpm of the required speed.
5. The suction and discharge heads of zero discharge were read on the manometers and current and voltage readings made.
6. The discharge value was opened until the desired discharge was reached as indicated on the recorder.
7. The speed was readjusted.
8. The manometers were read for the discharge and suction heads, and current voltage readings made.
9. The discharge was increased in even increments repeating

the adjustment of speed each time and the reading of the manometers, voltage, and currents. The voltage was readjusted to 240 volts if it varied too much from this value.

In testing the pumps in parallel the essential variations in procedure were as follows:

1. Both pump speeds were adjusted to near the required value.
2. The valves controlling the return flow to the tanks were adjusted to give the total discharge desired.
3. Valves before the wye were adjusted to give the same rate of flow from each pump.
4. Speeds and discharges were adjusted until the required values were established in both pumps. The speeds were adjusted to within ± 2 rpm of the desired speed.
5. Readings of manometers, currents, and voltages were made.
6. Speeds were rechecked for variation.
7. The speed was reduced by the desired amount in one pump. The speed in the other pump was readjusted if necessary.
8. Readings of manometers, currents, voltages, and flow records were made.
9. Speeds were rechecked for variation.
10. A further reduction of speed in one pump was made and the test continued in the same manner.

In the tests in which one pump was pumping water and another was pumping a water-solids mixture, the two pumps were adjusted to the desired test speed, and then the valves in the line were opened and adjusted until the desired discharge was obtained. The discharges used were the same in both lines. The suction side manometer was turned on only after flow had been established. The test was continued until the liquid in the smaller supply tank was exhausted.

Because the pumped fluid could not be recirculated to the supply tanks, the duration of the test was limited to about 45 seconds. In view of the brevity of the test, movie cameras were used to take filmed records of the manometer readings and the electric current and voltage readings.

Measurements of head loss were made for various combinations of discharge in the two legs of the wye. First, the required discharges were established in each line by adjusting the valves upstream of the wye. Then, pressure differences between the upstream side of the wye and the downstream side of the wye were made. These readings included the difference between the pressure in each upstream leg and the pressure at a section immediately downstream of the wye, and, also, the difference between the same upstream pressure and the pressure at a section five feet downstream of the wye. In the first tests the measurement at each location was the average obtained from two or three piezometer taps located about the periphery of the pipe. In later tests, individual readings were made for each piezometer tap at the upstream locations.

C. <u>Data</u>

The experimental data obtained are given in the Appendix. A large number of experimental runs not shown were made in an attempt to obtain impellers which produced characteristic curves which were similar. It also should be noted that the supply tanks were not interconnected for runs No. 196 through 217 during which the pumps were operated in parallel. This resulted in variable suction heads on the two pumps. These data were not used in the analysis. Another point to be noted is that due to motor power limitations, it was not possible to obtain readings for the higher discharges at high speeds.

The pump data were reduced in the following manner. The product of the current reading and the voltage gives the power input in watts. Use of the calibration curve for the motor gives the brake horsepower. The algebraic sum of the discharge and suction pressures and velocity heads in the suction and discharge pipes yields the head of the pump in pounds per square inch. The power output is obtained from the following expression:

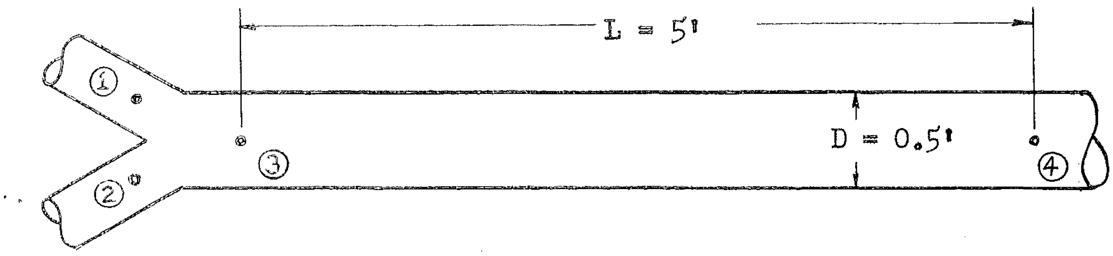
$$WHP = \frac{\gamma Q H}{550}$$

The pump efficiency is then found by

$$e = \frac{WHP}{BHP} (100) \text{ per cent}$$

Head losses in the wye were calculated from the piezometric head measurements between points 1 and 2 upstream of the wye and points 3 and 4 downstream of the wye. The basic equation used to determine the head loss is an energy equation written between points 1 and 2 and the downstream point (Sketch No. 1). Using the downstream point 4, for instance, we have:

$$Q_1 \left(h_1 + \frac{V_1^2}{2g}\right) + Q_2 \left(h_2 + \frac{V_2^2}{2g}\right) = Q_4 \left(h_4 + \frac{V_4^2}{2g}\right) + Q_4 H_L + Q_4 h_f$$



SKETCH NO. 1

in which H_L is the head loss in the wye and h_f is the frictional head loss for the five-foot length of pipe from point 3 to point 4. Dividing by Q_4 gives:

$$\frac{Q_1}{Q_4}\left(h_1 + \frac{V_1^2}{2g}\right) + \frac{Q_2}{Q_4}\left(h_2 + \frac{V_2^2}{2g}\right) - \left(h_4 + \frac{V_4^2}{2g}\right) - h_f = H_L$$

Since $\frac{Q_1}{Q_4} + \frac{Q_2}{Q_4} = 1$ this expression may be written as

$$H_L = \frac{Q_1}{Q_4}\left(h_1 - h_4 + \frac{V_1^2 - V_4^2}{2g}\right) + \frac{Q_2}{Q_4}\left(h_2 - h_4 + \frac{V_2^2 - V_4^2}{2g}\right) - h_f \tag{6}$$

The quantities $(h_1 - h_4)$ and $(h_2 - h_4)$ were measured with differential manometers, while Q_1 and Q_2 were determined by flow meters. The velocities were calculated from the rates of flow and the pipe areas. The quantity h_f was found from

$$h_f = f \frac{L}{D} \frac{V_4^2}{2g} \tag{7}$$

In equation (7), f was found from the Moody diagram using a pipe roughness of 0.0002 ft. The length L was 5 feet and D was 0.5 ft. Calculation of the head loss using measurements at point 3 followed in the same way except that the term h_f did not appear in the equation.

IV. ANALYSIS OF RESULTS

A. Similarity of Pumps

Figures 3, 4, and 5 compare the characteristics of the two model pumps as determined by the tests of each pump singly. It can be seen that the departures from similarity of these two pumps are small.

B. Combined Pump Tests, Different Speeds

Figures 6 through 17 show the results of the combined pump tests superimposed upon the curves of Figures 3, 4, and 5. Scales showing prototype discharge and brake horsepower are also given. It can be seen that the effect on pump 2 of a slight decrease in speed of Pump 1 is relatively small. At the higher discharges there is a slight increase in discharge in Pump 2 when the speed in Pump 1 is decreased. It is believed that this can be explained in the following way.

Referring to Figure 18, let it be supposed that both pumps are operating at the same speed, N, and the same discharge, $Q_1 = Q_2$. The points of operation are located by the intersection of a system head curve with the appropriate pump head discharge curve. When the speed of Pump 1 is decreased to N^1 operation takes place along a new head discharge curve indicated by a dashed line. Also, since the rates of flow in each approach pipe of the wye have changed, each system head curve is varied slightly. Pump 2, however, is still operating along the same head discharge curve since its speed has not changed. Thus, the operating point for Pump 2 moves down to the right along the curve for constant speed, whereas the operating point for Pump 1 moves to the intersection of a new system head curve and a head discharge curve for a lower speed.

C. <u>Combined Pump Test, Different Fluids</u>

A single test was made with water being pumped by one pump and a water-solids mixture being pumped by the other pump. Results are given in Table I. For the pump handling slurry, a comparison is presented together with results obtained earlier for the pump operating singly (1). The results for the pump handling water are not comparable since, in this test, the pump volute of the water pump was leaking through a crack which appeared in an earlier test. The corresponding prototype speed and discharge were 157 rpm and 48,400 gpm, respectively.

Pump No.	Operating Condition	Fluid Density g/l	Pump Head psi	Brake Horsepower	Efficiency %
1	Combined Pump	1,150	26.4	16.8	70
1	Single Pump	1,150	27.5	15.5	79
2	Combined Pump	1,000	24.2	17.48	61

TABLE I - COMBINED PUMP PERFORMANCE-DIFFERENT FLUIDS

Although the results show a decreased head and increased brake horsepower with a resulting decrease in efficiency for the water-solids pump in the combined test, it is felt that the result from a single test is inconclusive. The result for the single pump represents an average obtained from a number of experimental points. Also, accurate control of pump speed and discharge which was possible in the single pump test was impossible in the test with different fluids, because of the short duration of the test.

Duplication of actual operating conditions in the laboratory for this problem has proved to be time-consuming and difficult. The condition in which two dredge pumps are pumping water-solids mixture into a common pipeline under essentially the same conditions followed by one pump handling water while the other pump still pumps water-solids mixtures could be expected to be a common occurrence in dredging operations. Such an occurrence would be hard to duplicate in a laboratory installation.

From an analytical viewpoint, however, it would appear that if the pump handling a water-solids mixture were kept at constant speed, the effect of the change in fluid density in the other pump would be to increase the discharge of the water-solids pump. If the pump were to operate at constant speed it could be assumed that its characteristic head-discharge curve would remain unchanged. The combined flow beyond the wye would have about one half of the volume of solids that it formerly had. This reduction would reduce the viscosity of the pumped fluid and also the head loss beyond the wye. The water solids pump would be in effect, working against a reduced head and a somewhat higher discharge could be expected. The change would be dependent mainly upon the length of pipe line after the wye.

It is possible that the flow is such that the change in viscosity of the fluid would have a negligible effect upon the head loss for high Reynolds numbers. In this instance, the water-solids pump would continue to operate with essentially the same discharge and efficiency.

D. Head Losses in the Wye

Results of head loss measurements in the wye are presented in Table II. The method by which these results were obtained from the piezometric measurements will be explained.

Initial studies of the head loss in the wye indicated an asymmetry in the flow through the wye. This asymmetry may be illustrated as follows. Let us suppose that a flow rate of Q occurs in one leg of the wye and a flow rate of 2Q occurs in the other leg. Changes in head across the wye are measured. Then the situation is reversed with 2Q in the first leg of the wye and Q in the second leg. Changes in head across the wye are again measured and are found to vary considerably from those measured first. This would not be expected to occur if the flow were symmetrical.

To obtain more information about the flow in the wye, piezometer taps were drilled at the top, at the center on one side, and at the bottom of the approach pipes of the wye at the upstream locations. The lines to the manometers were arranged so that each tap could be read separately. The data obtained for various flow conditions are tabulated in the Appendix. It can be seen that the readings for a given rate of flow in the wye vary considerably depending on the location of the tap and, also, that the variations are quite consistent in that the three readings nearly always rank, in size, in the same order.

This suggests the possibility of secondary flow in the pipe which may possibly be caused by the elbow upstream. While this is of some interest, it was felt that a good, conservative estimation of the head loss in the wye could be obtained from these data. To obtain more correct values would entail considerably more time and effort. Accordingly, head loss calculations were made based upon the piezometer readings giving the largest head loss across the wye.

Another comment on the head loss calculations which should be made is that they were based upon a downstream piezometric measurement five feet beyond the wye with an estimated friction loss for the intervening pipe length subtracted. Readings were also taken immediately downstream; these readings gave less consistent values due, perhaps, to the proximity of the tap to the wye.

A coefficient of loss for the pipe was calculated and is included in the table. It was taken to be equal to the head loss divided by the velocity head of the combined flow. Figure 19 shows a plot of the loss coefficient versus the ratio of flow in the two legs of the wye.

An interesting conclusion may be drawn from a study of the losses in the wye. If only one line is operated through the wye or if the flow in one line is considerably less than the other, the wye is rather inefficient. The results of the test show that when the ratio of the separate flows is 1 to 3 the loss is about three times that of the case when the two flows are equal. When there is flow in one leg only, the loss is ten times that of the case with equal flows. In the experiment, the loss in the wye was found to be about equivalent to that which could be expected in a three foot length of 6-inch pipe. This high loss is probably due to an eddy forming in the inactive leg of the wye.

V. CONCLUSIONS

The effect on one pump of a change in speed of another pump operating in parallel was found to be small. A reduction in efficiency of 1.5% was the maximum change observed at a prototype discharge of 64,000 gpm. No definite trends could be observed at the lower pump speeds. The chief effect on the pump operating at constant speed was a slight increase in discharge, presumably caused by the alteration of the loss characteristics of the wye with the changed condition.

The minor disadvantageous effects that the change in conditions for one pump might have on the other pump in a combined system would appear to be considerably outweighed by the added head loss which would be incurred if the two pumps were pumping through separate pipes.

A value of 0.14 was obtained for the loss coefficient in the wye which is defined as the ratio of the head loss to the downstream velocity head. The loss for flow through one leg of the wye alone was found to be about ten times as large, with intermediate values for intermediate ratios of flow in the two legs.

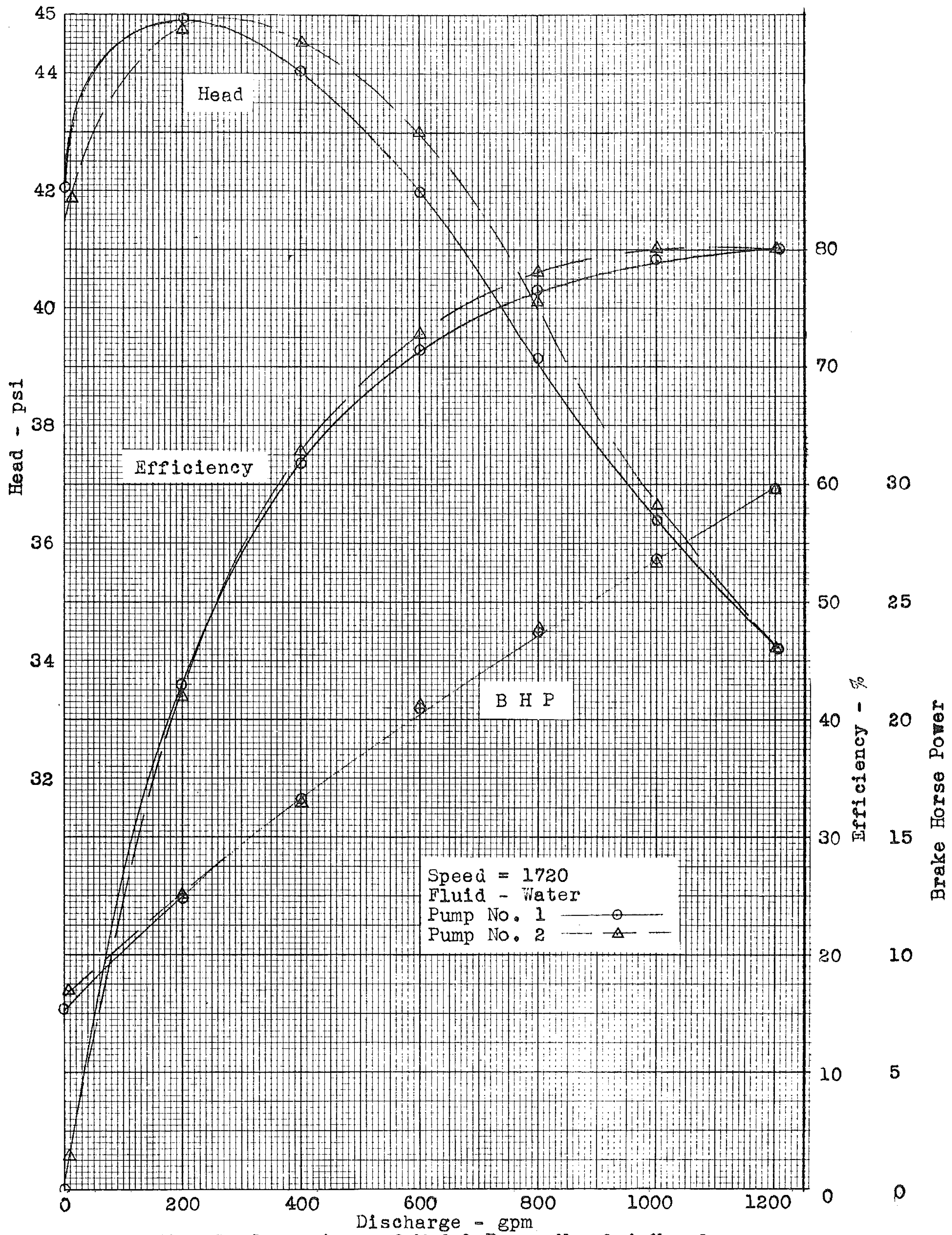


Fig. 3 Comparison of Model Pumps No. 1 & No. 2

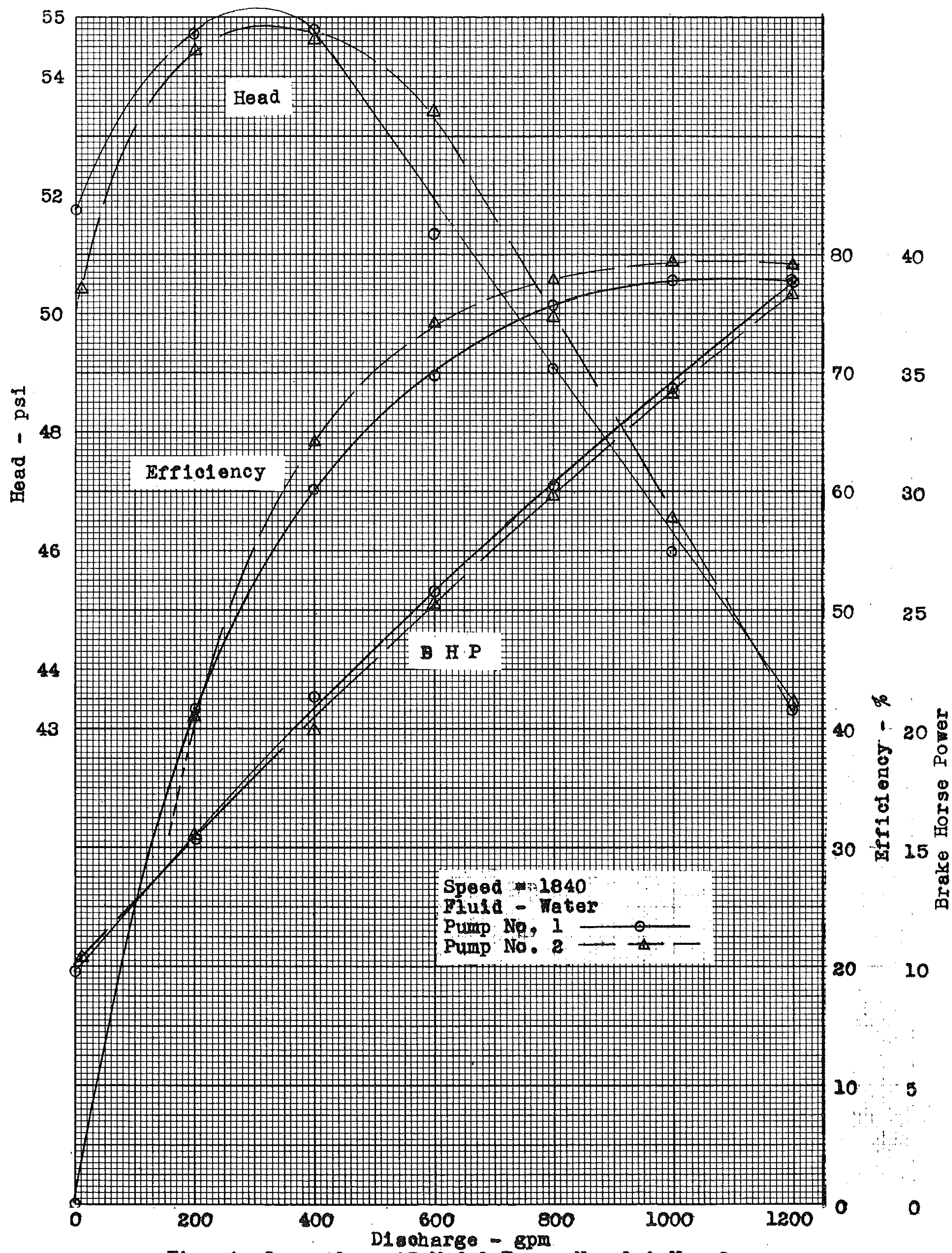


Fig. 4 Comparison of Model Pumps No. 1 & No. 2

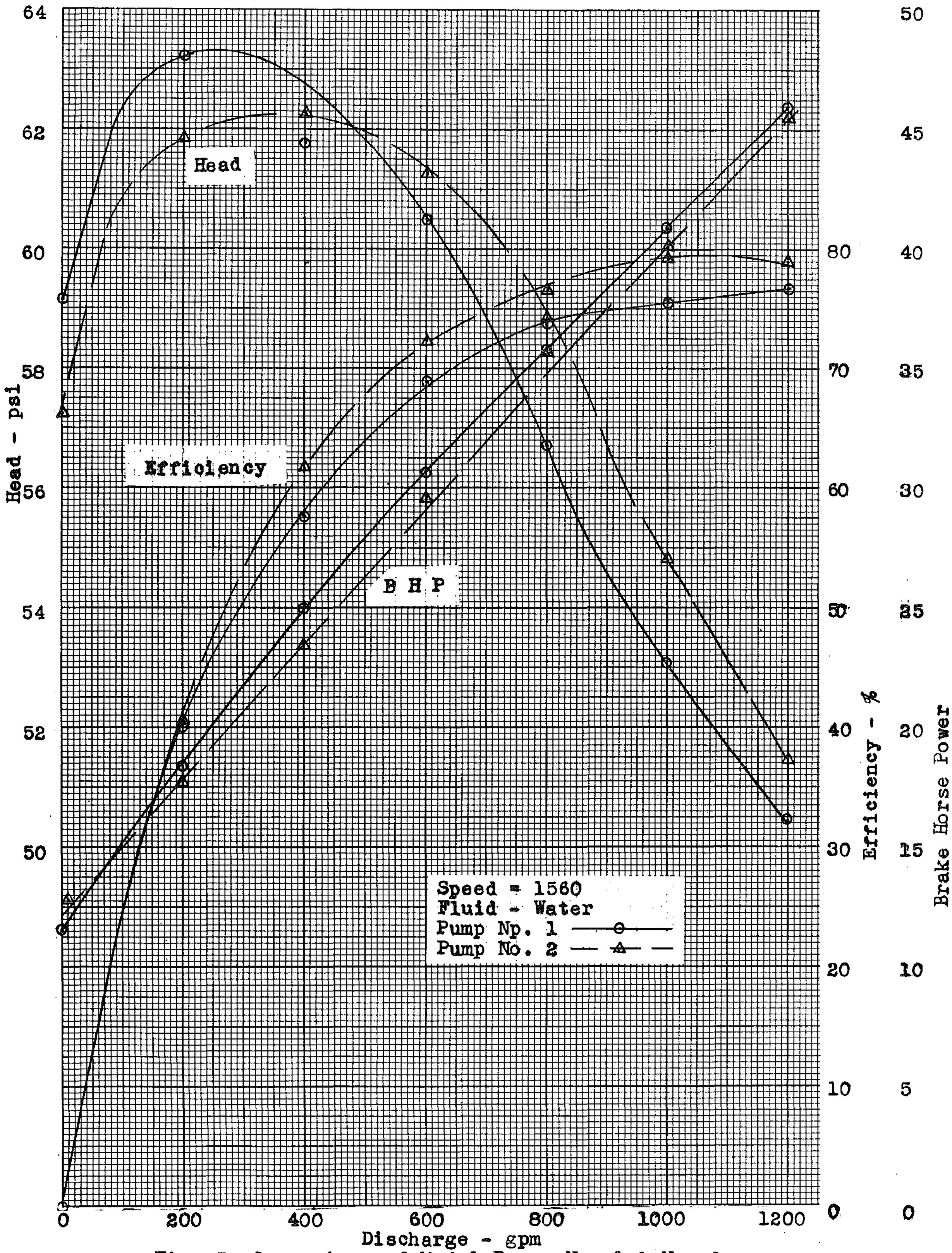


Fig. 5 Comparison of Model Pumps No. 1 & No. 2

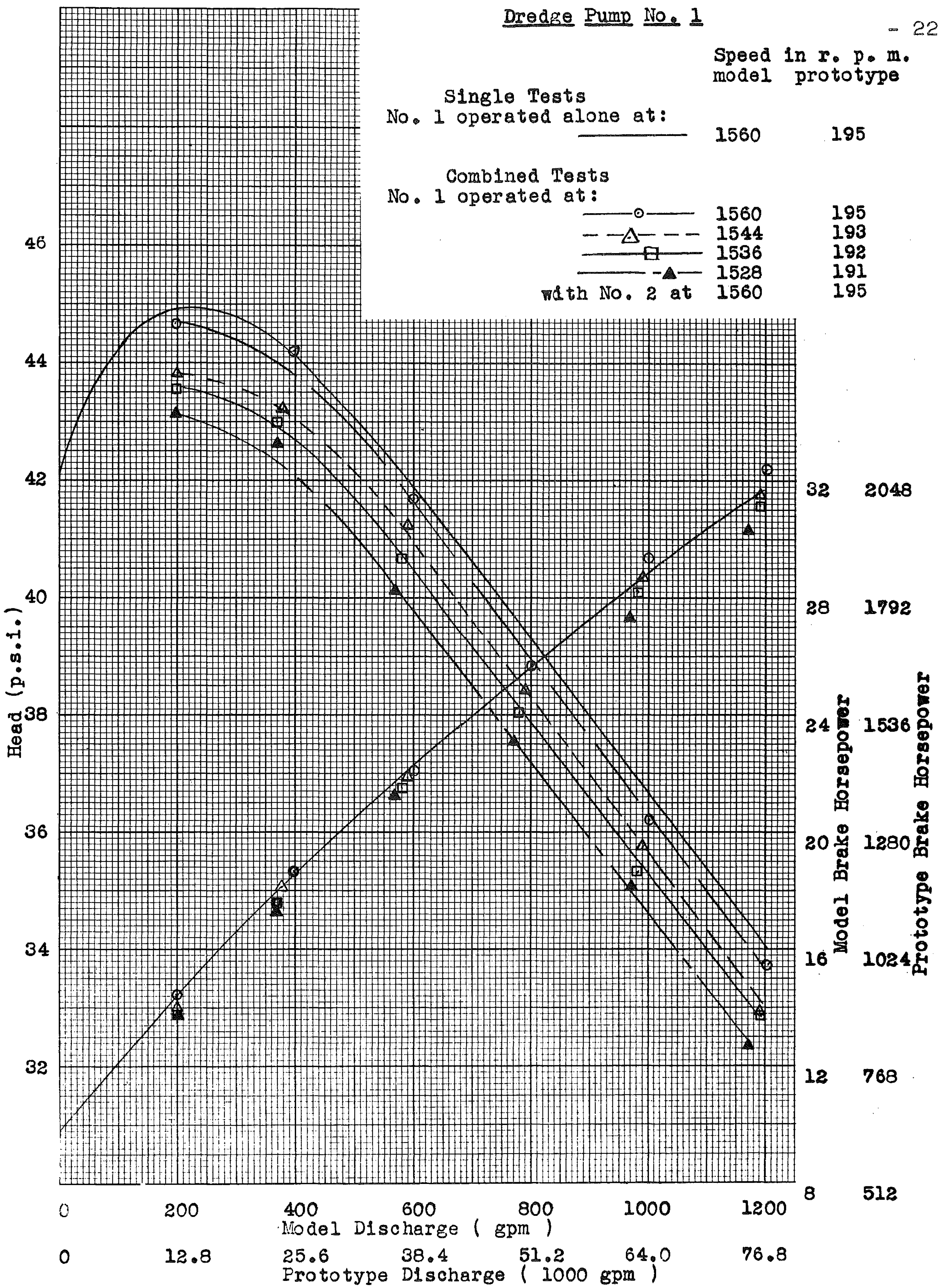


Fig. 6 Head and Brake Horsepower as a Function of Discharge

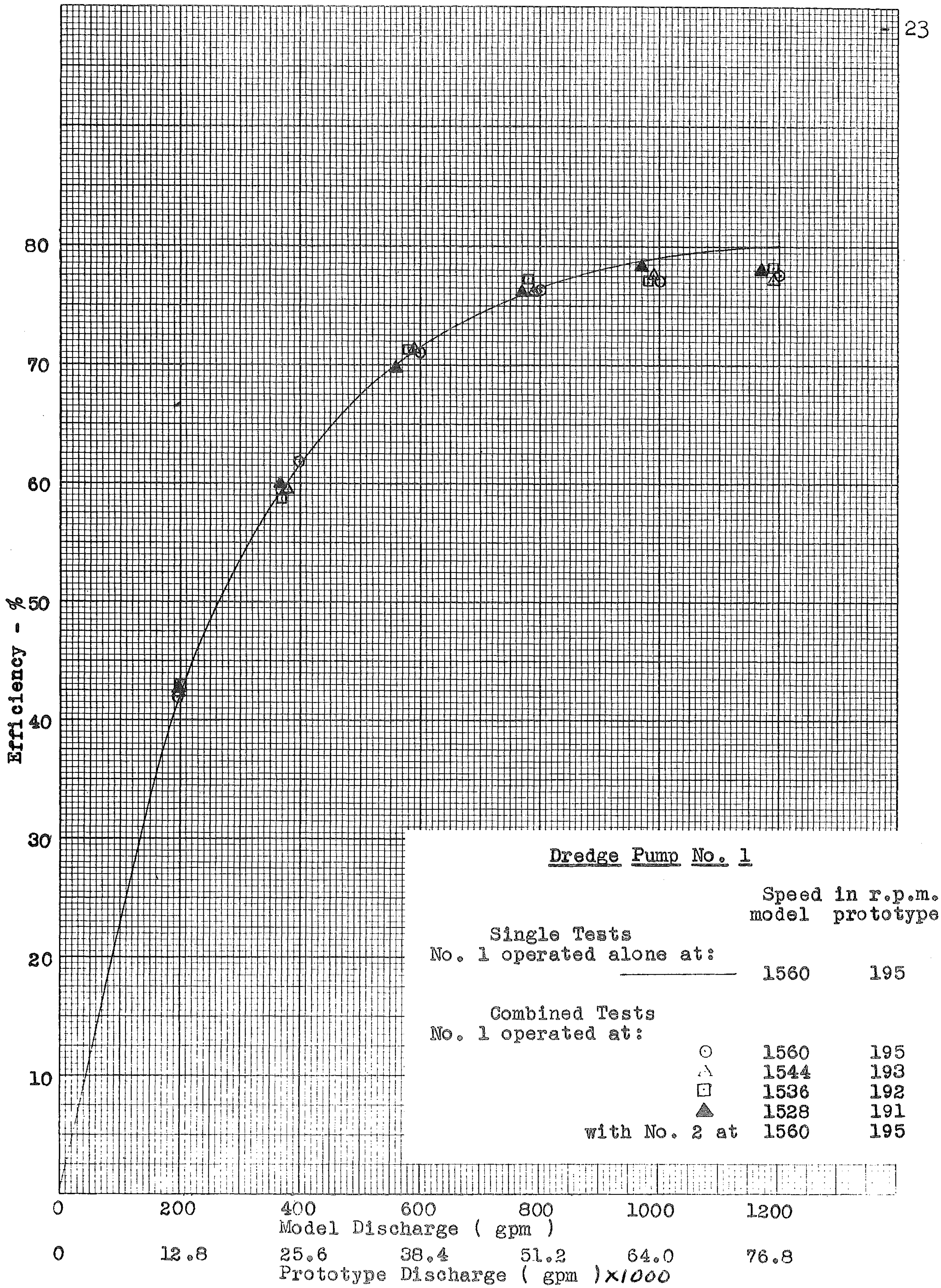


Fig. 7 Efficiency as a Function of Discharge

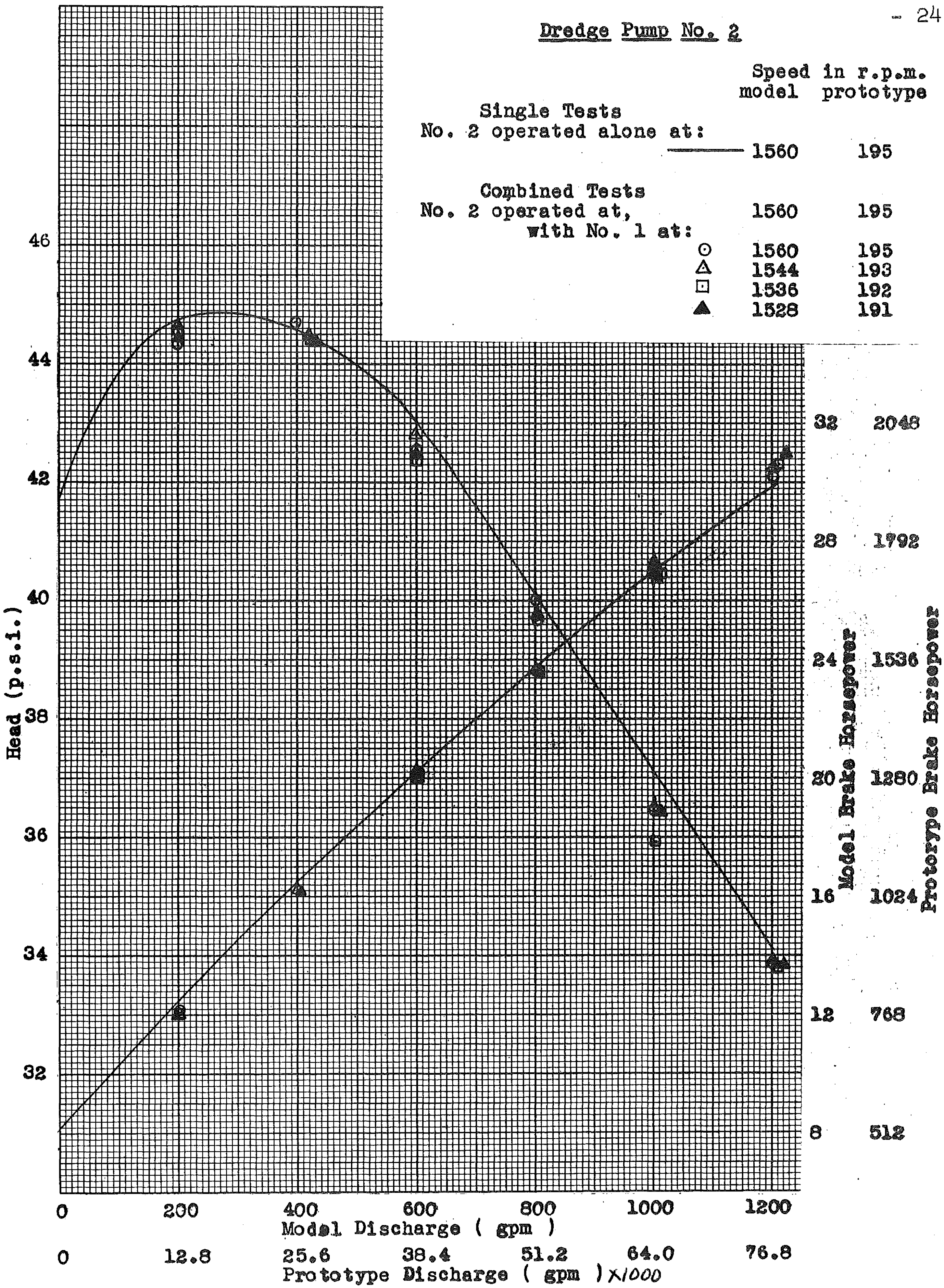


Fig. 8 Head and Brake Horsepower as a Function of Discharge

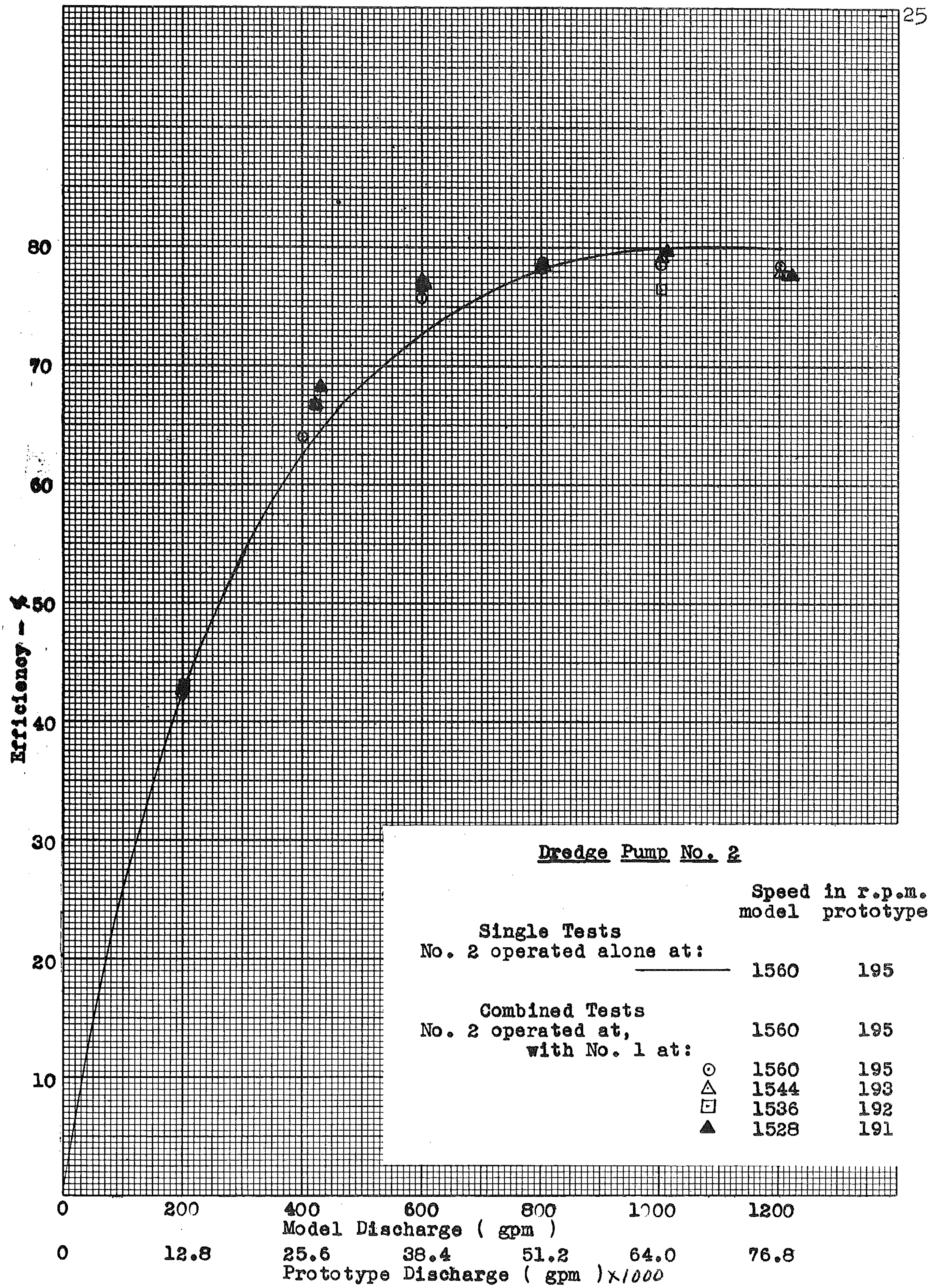


Fig. 9 Efficiency as a Function of Discharge

Dredge Pump No. 1

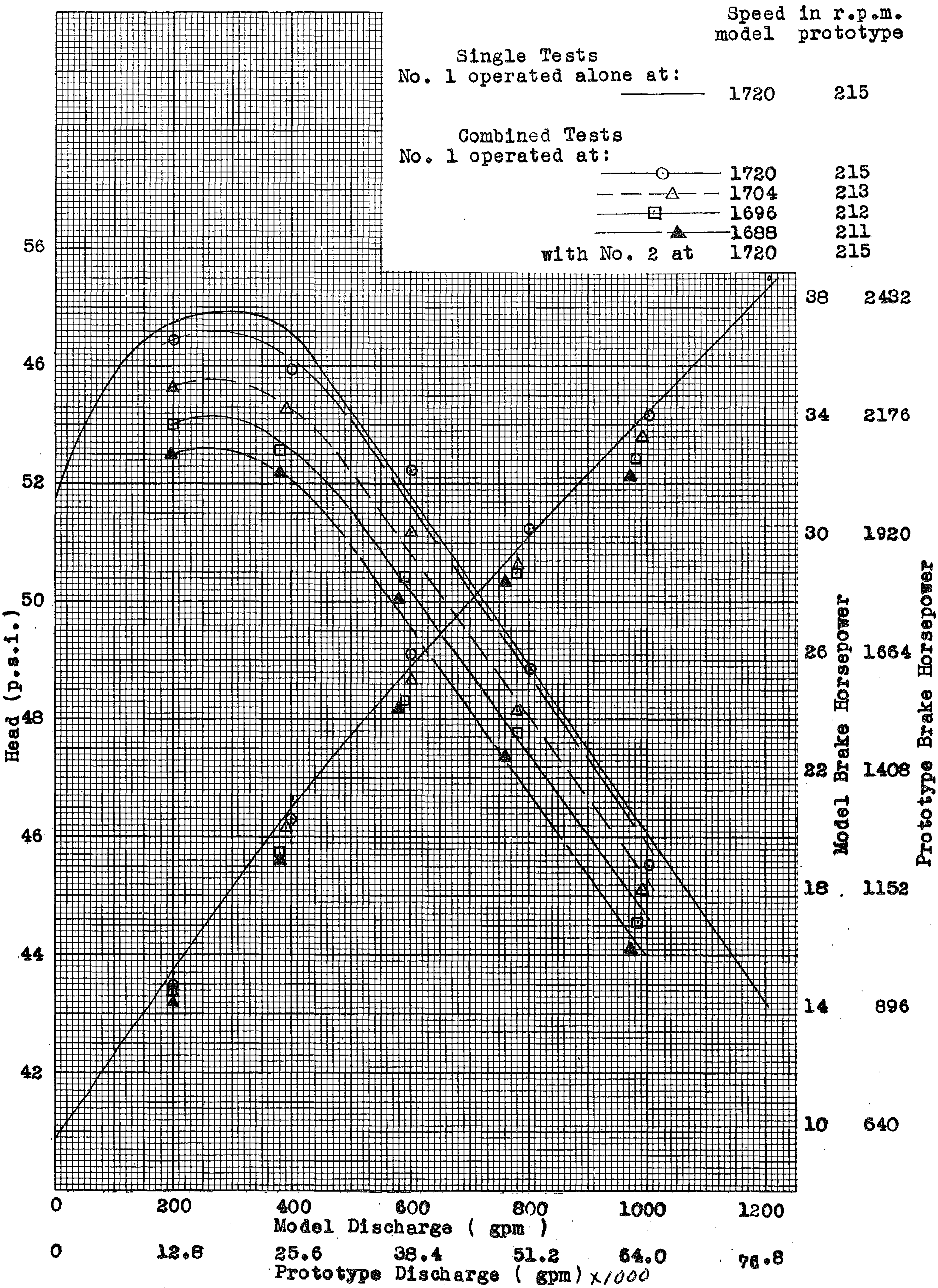


Fig. 10 Head and Brake Horsepower as a Function of Discharge

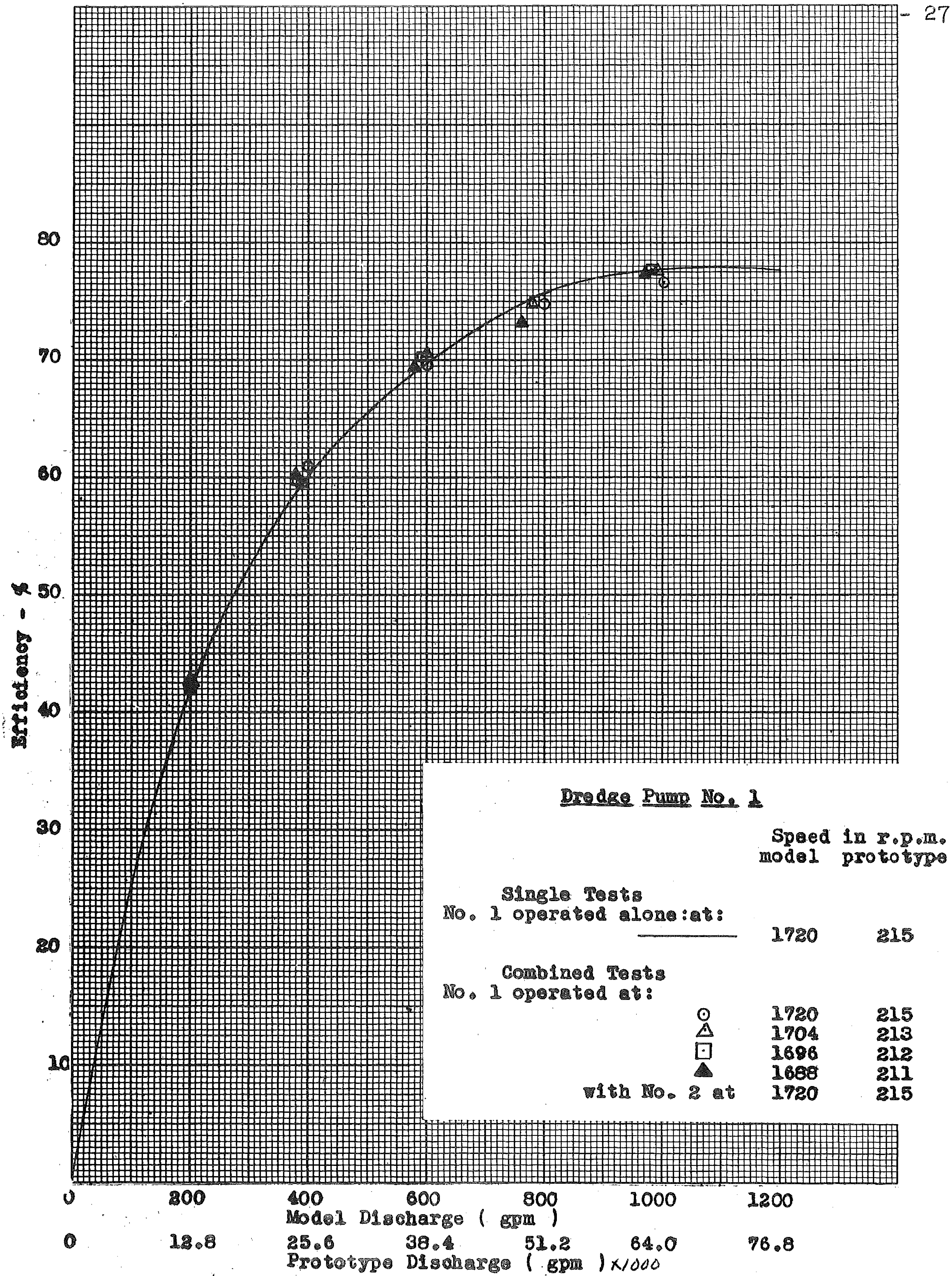


Fig. 11 Efficiency as a Function Of Discharge

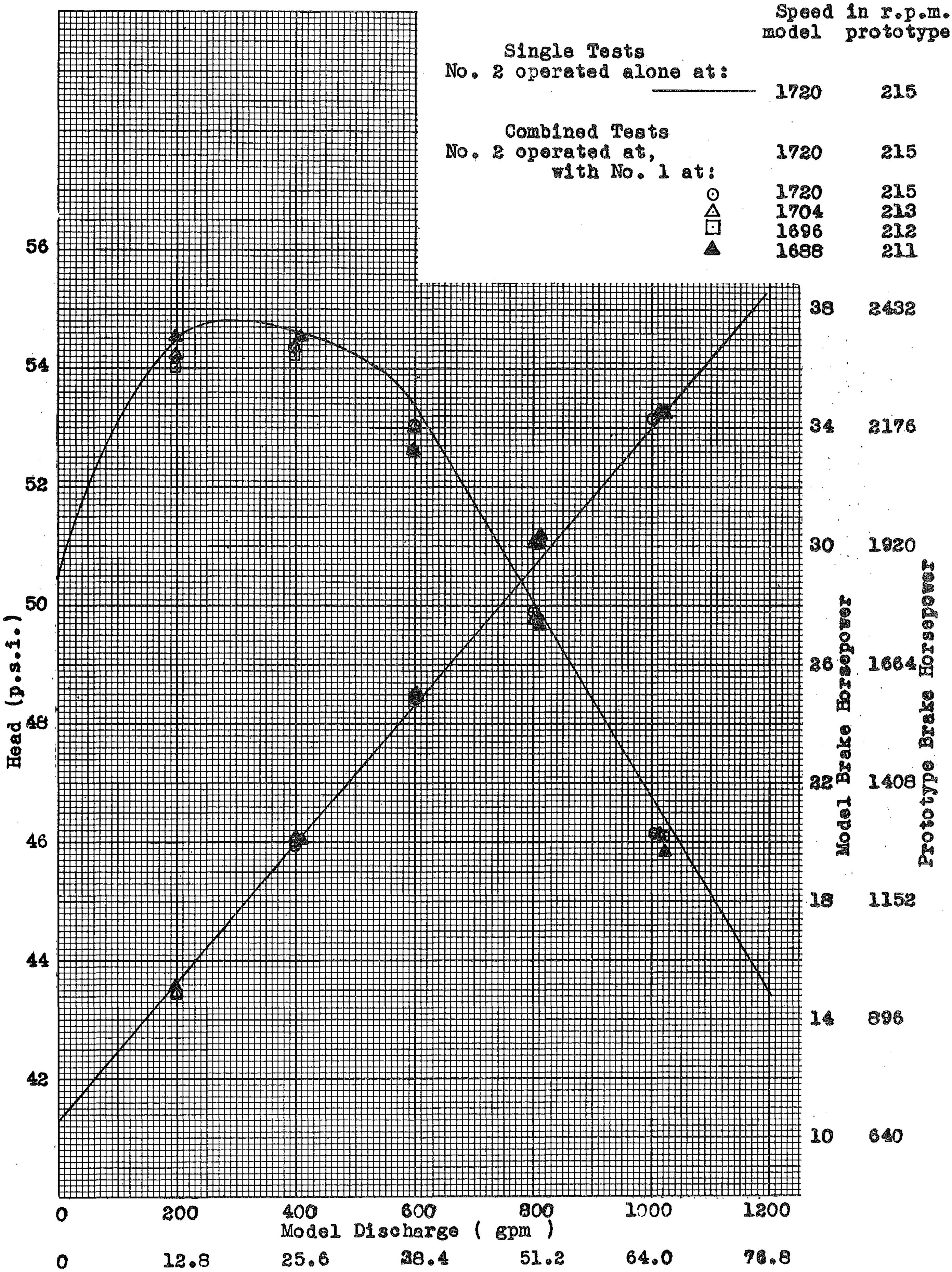


Fig. 12 Head and Brake Horsepower as a Function of Discharge

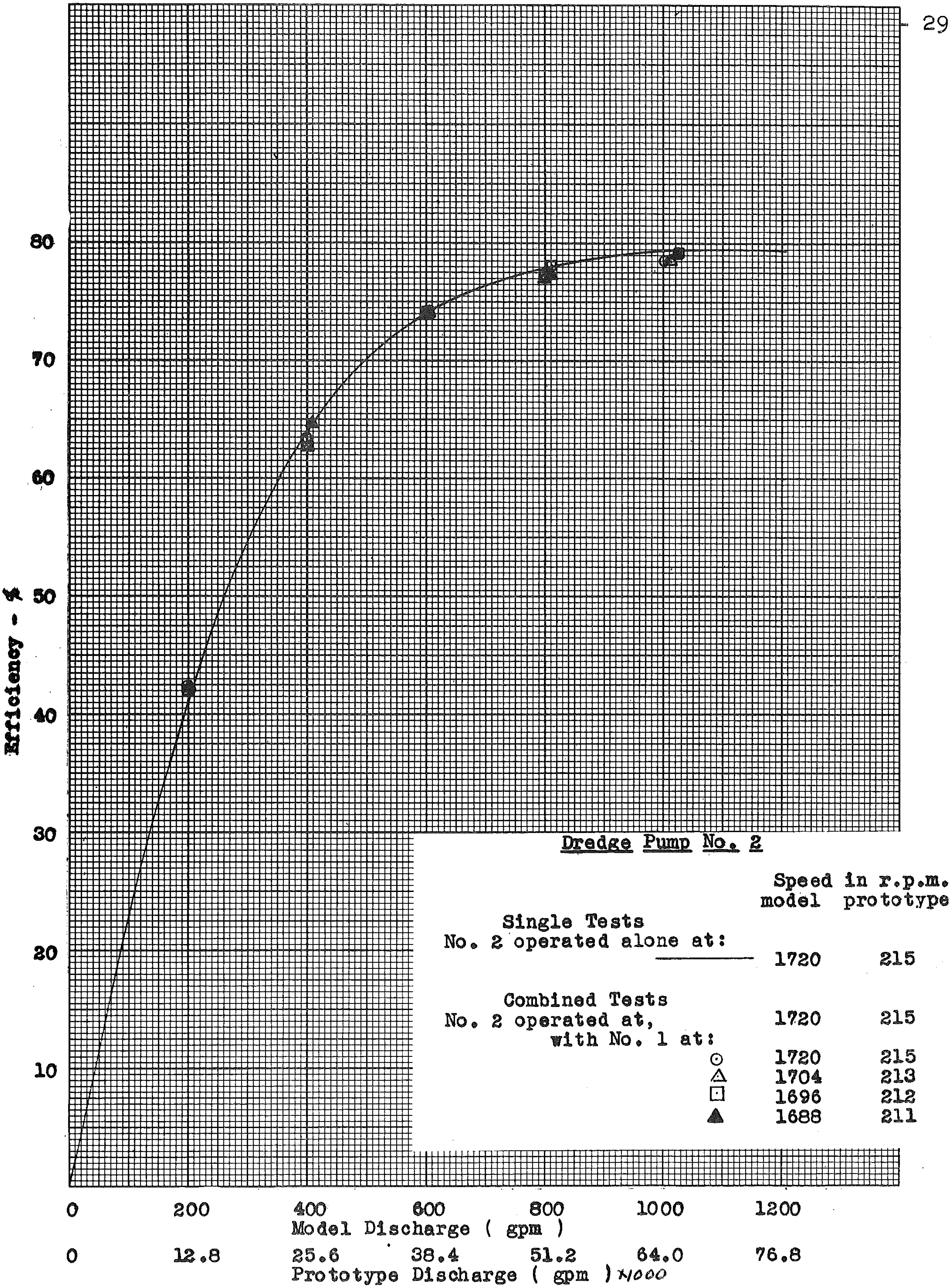


Fig. 13 Efficiency as a Function of Discharge

Dredge Pump No. 1

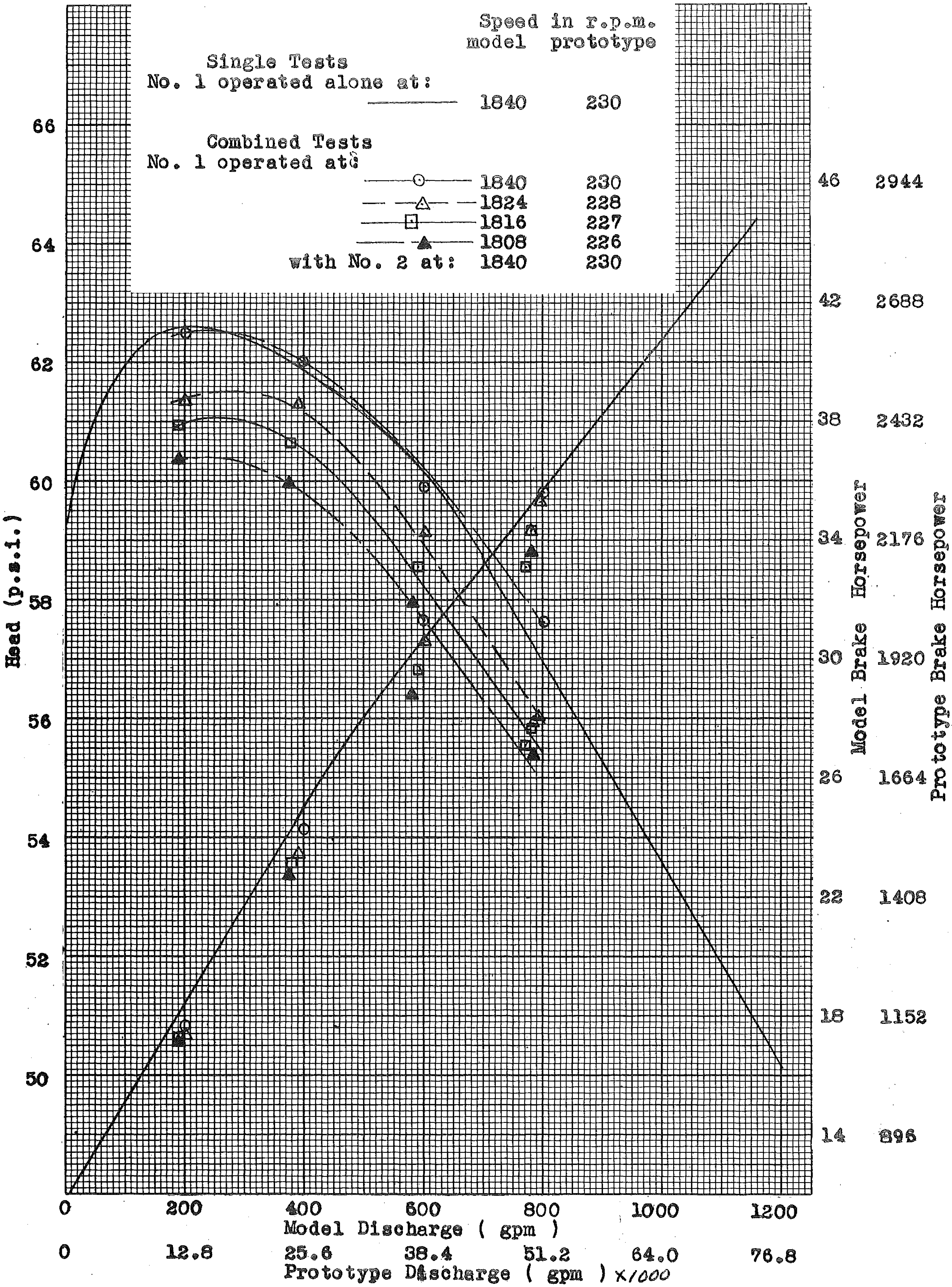


Fig. 14 Head and Brake Horsepower as a Function of Discharge

Dredge Pump No. 2

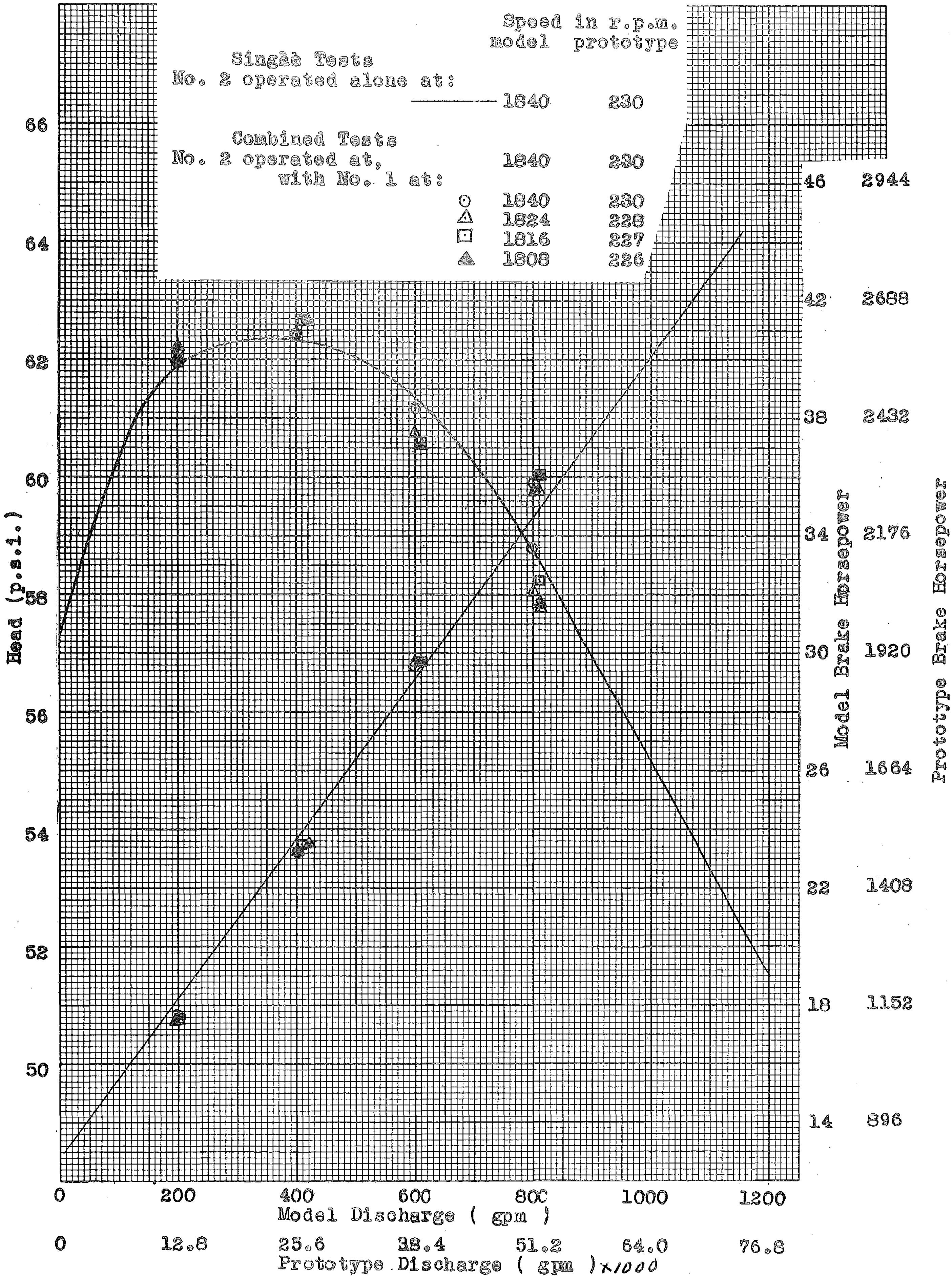


Fig. 15 Head and Brake Horsepower as a function of Discharge

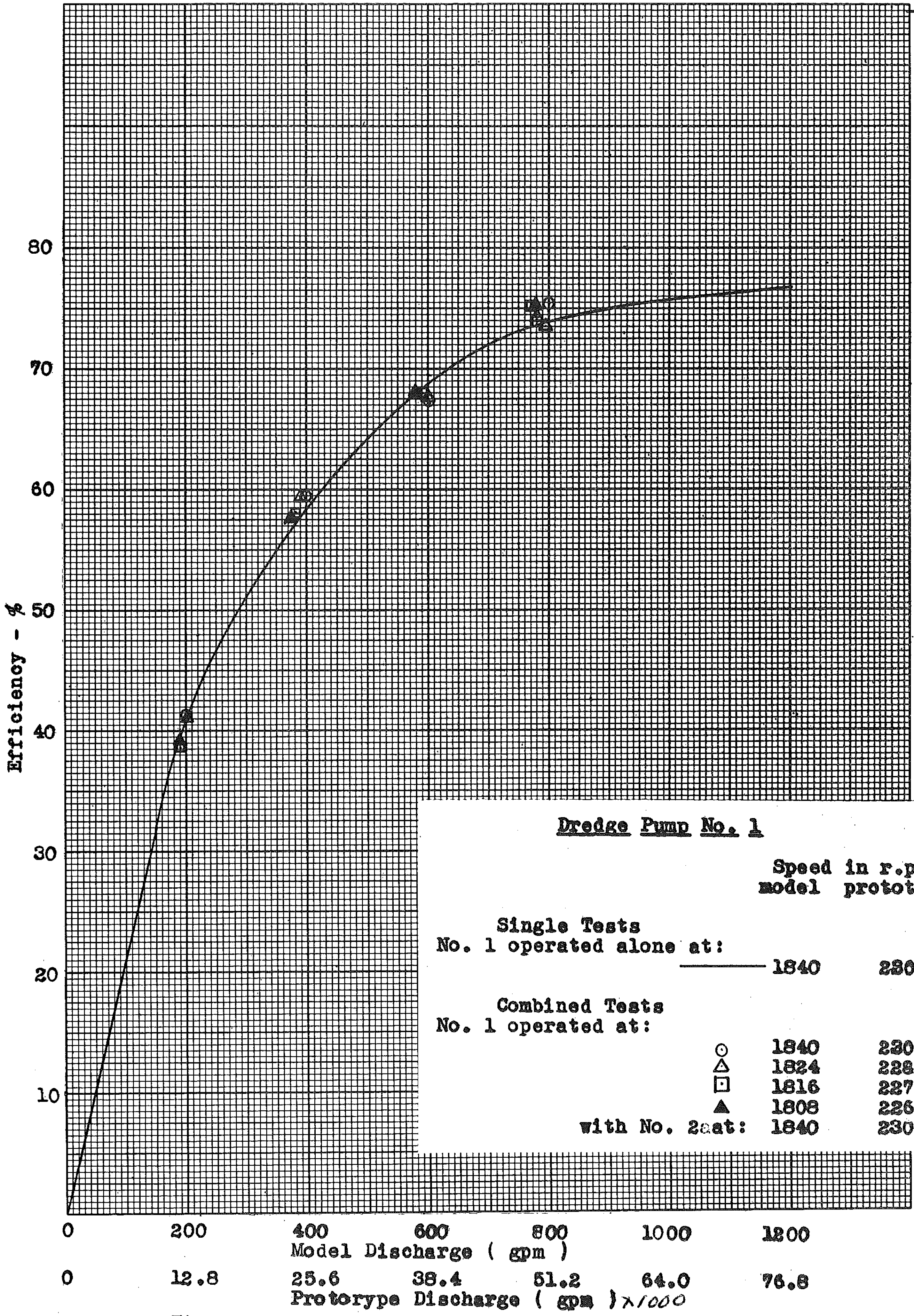


Fig. 16 Efficiency as a Function of Discharge

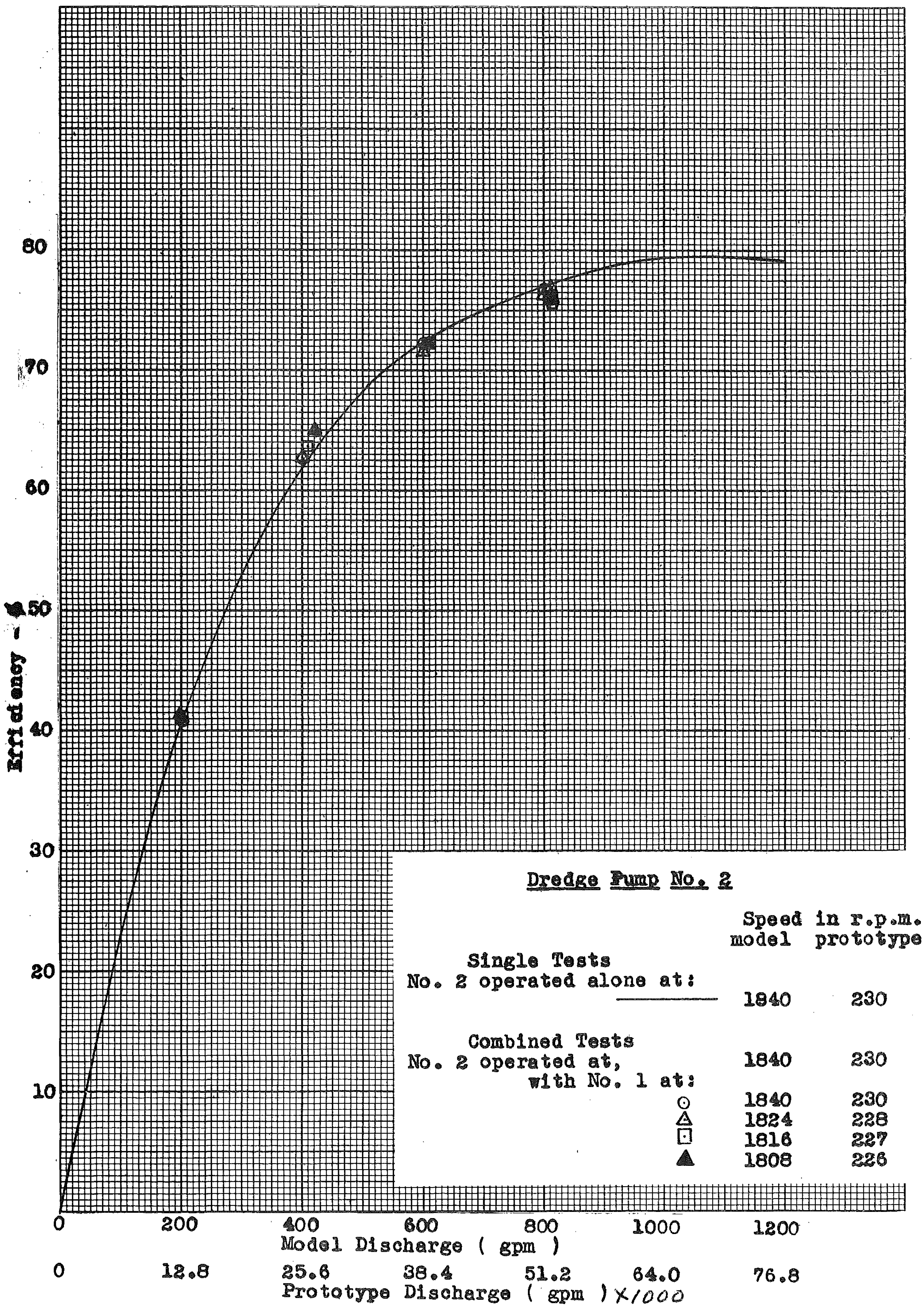


Fig. 17 Efficiency as a Function of Discharge

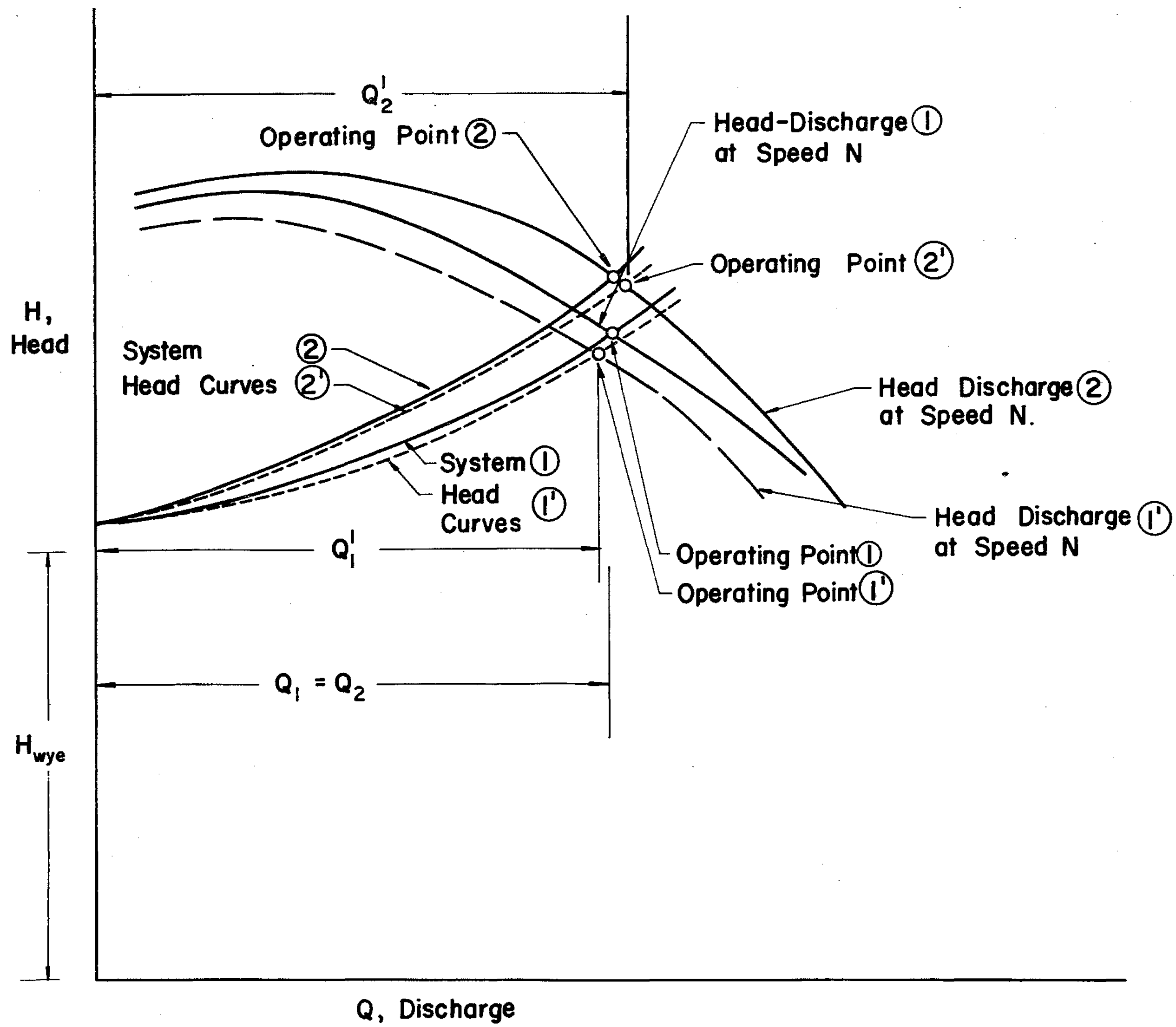


FIG. 18 TWO PUMPS IN PARALLEL HYPOTHETICAL SYSTEM HEAD CURVES AND PUMP HEAD-DISCHARGE CURVES

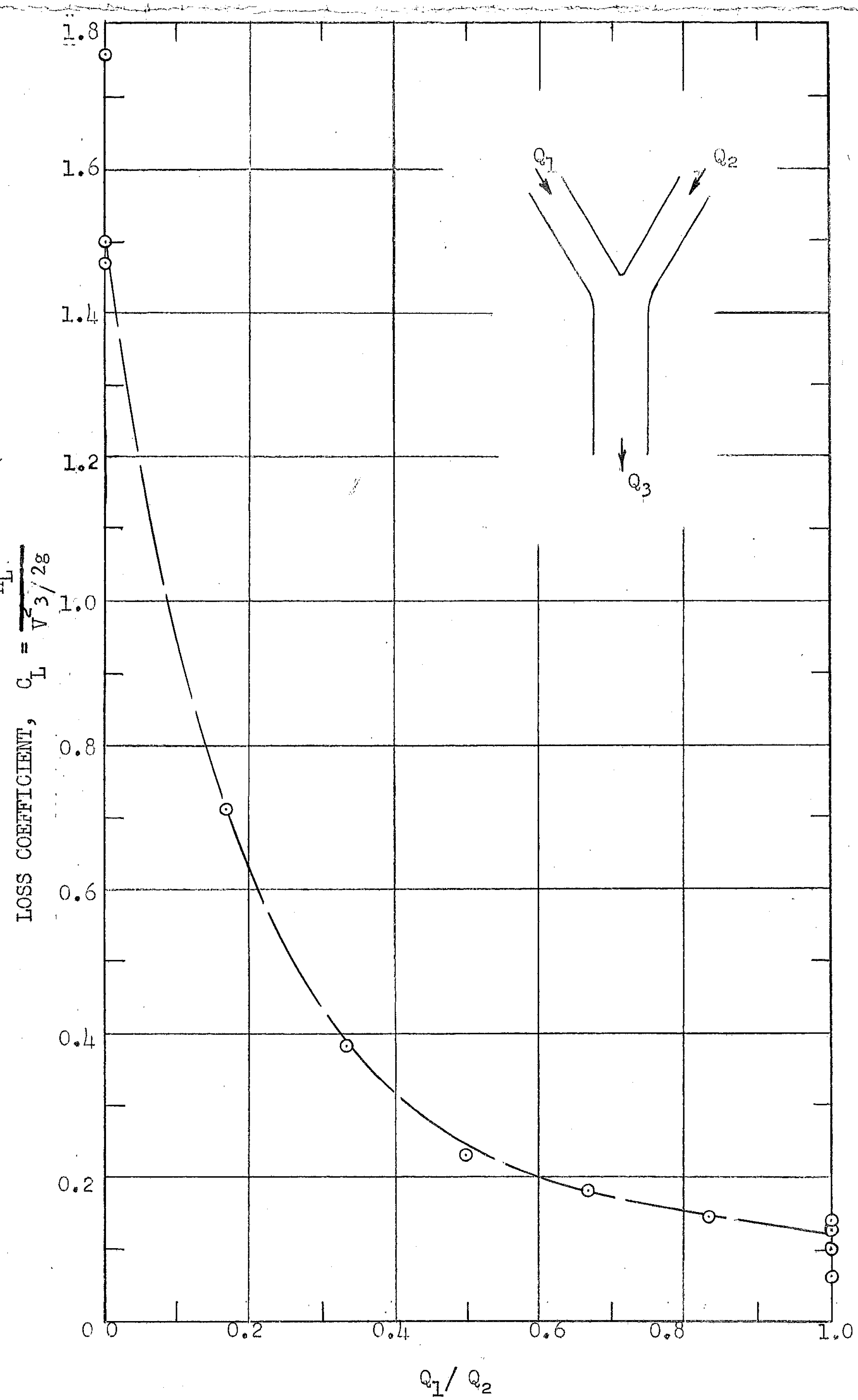


Fig. 19 Loss Coefficient as Function of

Discharge Ratio in Wye

Q_1 gpm	Q_2 gpm	Q_3 gpm	H_L Ft. of Water	C_L $H_L / \frac{V^2_3}{2g}$
200	200	400	.02	.06
400	400	800	.16	.12
600	600	1200	.39	.14
800	800	1600	.52	.10
1000	1000	2000	1.03	.13
1200	1200	2400	1.63	.14
1000	1200	2200	1.39	.14
800	1200	2000	1.48	.18
600	1200	1800	1.50	.23
400	1200	1600	2.02	.38
200	1200	1400	2.80	.71
0	1200	1200	4.24	1.50
0	1200	1200	4.33	1.50
1200	0	1200	5.08	1.80

TABLE II HEAD LOSSES AND LOSS COEFFICIENTS IN WYE

Run No.	Q_1 gpm	Q_2 gpm	$h_1 - h_4$ ft. of Water			$h_2 - h_4$ ft. of Water			$h_1 - h_3$ ft of Water	$h_1 - h_4$ ft of Water
			T	C	B	T	C	B	C	C
302	1200	0	-7.05	-6.90	-6.11	-3.79	-3.54	-3.14		
303	0	1200	-3.56	-3.74	-3.82	-6.86	-7.37	-7.50		
305	1200	1200	0.19	-0.68	0.72	0.34	-0.81	-0.39	-3.15	-3.27
306	1000	1200	0.73	0.08	1.06	-0.49	-1.64	-1.22	-1.95	-3.69
307	800	1200	0.60	0.36	0.94	-1.43	-2.60	-2.30	-1.28	-4.24
308	600	1200	0.28	0.08	0.50					
309	400	1200	-0.65	-0.60	-0.42	-4.27	-5.16	-4.94	-1.53	-6.15
310	600	1200				-3.00	-3.96	-3.61	-1.19	-5.15
311	200	1200	-1.43	-1.43	-1.43	-5.72	-6.50	-6.37	-2.37	-7.10
312	0	1200	-3.64	-3.77	-3.90	-6.95	-7.10	-7.56	-3.78	-7.47
313	1000	1000	-0.18	-0.68	-0.16	0.42	-0.42	0.11	-2.40	-2.16
314	800	800	-0.21	-0.42	0.21	-0.15	-0.55	-0.23	-1.56	-1.67
315	600	600	0	-0.26	0.15	0.11	-0.23	0.06	-0.89	-0.86
316	400	400	-0.10	-0.16	0.03	0.06	-0.06	0	-0.41	-0.32
317	200	200	0	-0.03	0.03	0	-0.02	-0.02	-0.13	-0.10

Note: T, C, and B indicate taps at top, center, and bottom of upstream pipe at measuring section.

TABLE III DATA SHEET FOR HEAD LOSS IN WYE

R E F E R E N C E S

(1) Herbich, J. B. and Vallentine, H. R.
EFFECT OF IMPELLER DESIGN CHANGES ON CHARACTERISTIC OF A MODEL DREDGE PUMP, Fritz Engineering Laboratory, Hydraulics Division, Project Report No. 33, September, 1961.

A P P E N D I X

T A B L E S O F E X P E R I M E N T A L D A T A

DATA SHEET

Single Tests
(Liquid density 1000 g/L)

PUMP No. 2
Pump Speed 1560 rpm

Run No.	Suction Head Psi	Discharge Head Psi	Discharge cfs	Brake Horse Power
154	+1.52	43.48	0.022	8.60
155	+0.19	44.87	0.445	12.37
156	-0.29	43.99	0.891	16.53
157	-1.25	41.21	1.337	20.68
158	-2.75	36.38	1.782	23.98
159	-4.35	30.77	2.228	26.72
160	-6.65	25.34	2.674	29.94

PUMP No. 2
Pump Speed 1720 rpm

Run No.	Suction Head Psi	Discharge Head Psi	Discharge cfs	Brake Horse Power
161	+1.66	52.06	0.022	10.40
162	+0.17	54.56	0.445	15.44
163	-0.20	54.20	0.891	19.88
164	-1.06	51.83	1.337	25.25
165	-2.60	46.35	1.782	29.94
166	-4.35	40.65	2.228	34.19
167	-6.65	34.33	2.674	38.32

PUMP No. 2
Pump Speed 1840 rpm

Run No.	Suction Head Psi	Discharge Head Psi	Discharge cfs	Brake Horse Power
168	+2.34	59.57	0.022	12.82
169	+0.48	62.61	0.445	17.77
170	-0.06	61.99	0.891	23.49
171	-1.06	59.71	1.337	29.65
172	-2.50	55.35	1.782	23.82
173	-4.10	49.18	2.228	40.22
174	-6.21	43.06	2.674	45.62

TABLE A-1

DATA SHEET

Single Tests
(Liquid density 1000 g/L)

PUMP No. 1
Pump Speed 1560 rpm

Run No.	Suction Head Psi	Discharge Head Psi	Discharge cfs	Brake Horse Power
175	+1.59	43.66	0.000	7.63
176	+0.53	45.37	0.445	12.24
177	-0.01	43.75	0.891	16.65
178	-0.96	40.47	1.337	20.55
179	-2.26	35.88	1.782	23.83
180	-3.80	31.06	2.278	26.84
181	-5.94	26.06	2.674	29.88

PUMP No.1
Pump Speed 1720 rpm

Run No.	Suction Head Psi	Discharge Head Psi	Discharge cfs	Brake Horse Power
182	+1.84	53.51	0.000	9.76
183	+0.49	55.15	0.445	15.34
184	-0.00	54.55	0.891	21.30
185	-0.67	50.14	1.337	25.78
186	-2.31	45.79	1.782	30.29
187	-3.93	40.51	2.228	34.41
188	-6.04	35.05	2.674	38.97

PUMP No. 1
Pump Speed 1840 rpm

Run No.	Suction Head Psi	Discharge Head Psi	Discharge cfs	Brake Horse Power
189	+2.04	61.22	0.000	11.58
190	+0.53	63.72	0.445	18.38
191	-0.01	61.54	0.891	25.00
192	-0.93	59.00	1.337	30.70
193	-2.21	53.52	1.782	35.87
194	-4.00	47.55	2.228	40.91
195	-5.97	42.27	2.674	45.94

TABLE A-1

DATA SHEET

Combined Tests
(Liquid Density 1000 g/l)

Note: Runs 196 to 217 were made with separate tanks.
Runs 218 to 291 were made with tanks interconnected.

Run No.	Pump No.	Pump Speed rpm	Suction Head psi	Discharge Head psi	Discharge cfs	Brake Horse Power
196	1	1560	+0.49	44.91	0.223	9.97
	2	1560	+0.73	44.59	0.223	10.15
197	1	1544	0.42	43.98	0.223	9.68
	2	1560	0.89	44.45	0.223	10.15
198	1	1536	0.39	43.20	0.223	9.40
	2	1560	0.91	44.54	0.223	10.15
199	1	1528	0.36	41.27	0.223	9.40
	2	1560	0.96	42.73	0.223	9.87
200	1	1560	0.16	45.14	0.445	12.29
	2	1560	0.29	45.10	0.445	12.17
201	1	1544	0.23	44.36	0.445	12.06
	2	1560	0.22	44.81	0.445	11.89
203	1	1536	0.14	43.66	0.445	11.72
	2	1560	0.27	45.10	0.445	12.17
204	1	1528	0.30	43.43	0.445	11.72
	2	1560	0.66	44.63	0.445	12.17
205	1	1560	0.10	44.81	0.668	14.64
	2	1560	0.06	44.40	0.668	13.87
206	1	1544	0.17	43.75	0.668	14.41
	2	1560	0.25	44.68	0.668	13.64
208	1	1536	0.22	43.28	0.668	14.06
	2	1560	-0.20	44.36	0.668	13.92
209	1	1528	0.17	42.88	0.646	13.82
	2	1560	-0.17	44.68	0.691	13.98
210	1	1560	-0.54	43.25	0.913	17.06
	2	1560	-0.20	44.54	0.891	16.31
211	1	1544	-0.43	42.60	0.891	16.53
	2	1560	-0.28	44.31	0.891	16.31
212	1	1536	-0.27	42.46	0.891	16.23
	2	1560	-0.41	44.31	0.891	16.07
213	1	1528	-0.18	41.99	0.867	15.95
	2	1560	-0.47	44.26	0.891	16.07

Table A-2

DATA SHEET

Combined Tests
(Liquid Density 1000 g/1)

Note: Runs 196 to 217 were made with separate tanks.
Runs 218 to 291 were made with tanks interconnected.

Run No.	Pump No.	Pump Speed rpm	Suction Head psi	Discharge Head psi	Discharge cfs	Brake Horse Power
214	1	1560	-1.28	40.24	1.325	20.71
	2	1560	-1.77	41.29	1.325	20.13
215	1	1544	-1.13	39.68	1.303	19.93
	2	1560	-2.89	40.92	1.325	20.22
216	1	1536	-0.91	39.49	1.281	19.36
	2	1560	-2.99	40.83	1.325	20.22
217	1	1528	-0.62	39.59	1.236	19.08
	2	1560	-3.09	40.92	1.325	20.22
218	1	1560	-1.25	39.96	1.325	20.13
	2	60	-0.96	41.06	1.325	20.02
219	1	1544	-1.18	39.54	1.303	19.84
	2	60	-0.91	41.34	1.325	20.02
220	1	1536	-1.15	39.03	1.281	19.55
	2	60	-0.91	40.92	1.325	20.02
221	1	1528	-1.10	38.44	1.258	19.26
	2	60	-0.88	41.06	1.325	20.31
222	1	1560	-2.45	35.37	1.782	23.73
	2	60	-2.24	36.79	1.782	23.69
223	1	1544	-2.40	35.04	1.760	23.25
	2	60	-2.18	36.61	1.782	23.69
224	1	1536	-2.31	34.81	1.738	22.39
	2	60	-2.16	36.56	1.782	23.69
225	1	1528	-2.21	34.40	1.716	22.11
	2	60	-2.31	36.46	1.782	23.69
226	1	1560	-4.15	30.51	2.228	27.39
	2	60	-3.95	31.00	2.228	27.12
227	1	1544	-4.00	30.28	2.206	26.66
	2	60	-3.98	31.00	2.228	26.95
228	1	1536	-3.88	29.95	2.183	26.20
	2	60	-3.57	30.81	2.228	27.35
229	1	1528	-3.80	29.80	2.161	25.34
	2	60	-4.05	30.81	2.250	26.95

Table A-2

DATA SHEET

Combined Tests
(Liquid Density 1000 g/1)

Note: Runs 196 to 217 were made with separate tanks.
Runs 218 to 291 were made with tanks interconnected.

Run No.	Pump No.	Pump Speed rpm	Suction Head psi	Discharge Head psi	Discharge cfs	Brake Horse Power
230	1	1560	-6.38	25.14	2.674	30.40
	2	60	-6.16	25.52	2.674	30.24
231	1	1544	-6.09	24.63	2.651	29.56
	2	60	-6.28	25.43	2.674	30.52
232	1	1536	-6.04	24.63	2.651	29.13
	2	60	-6.26	25.29	2.696	30.65
233	1	1528	-5.91	24.31	2.607	28.29
	2	60	-6.26	25.29	2.718	30.99
234	1	1720	0.39	54.78	0.445	14.99
	2	1720	0.36	54.51	0.445	14.94
235	1	1704	0.39	53.95	0.445	14.69
	2	1720	0.36	54.51	0.445	14.92
236	1	1696	0.39	53.34	0.445	14.69
	2	1720	0.36	54.33	0.445	14.92
237	1	1688	0.39	52.83	0.445	14.40
	2	1720	0.35	54.85	0.445	15.16
238	1	1720	-0.18	53.52	0.891	20.62
	2	1720	-0.13	54.09	0.891	19.93
239	1	1704	-0.16	52.88	0.869	20.33
	2	1720	-0.16	53.95	0.891	20.22
240	1	1696	-0.13	52.23	0.847	19.49
	2	1720	-0.18	53.86	0.891	20.13
241	1	1688	-0.11	51.86	0.847	19.20
	2	1720	-0.20	54.10	0.913	20.13
242	1	1720	-1.13	50.52	1.337	26.22
	2	1720	-0.91	51.59	1.337	25.02
243	1	1704	-1.06	49.54	1.337	25.38
	2	1720	-0.81	51.64	1.337	25.02
244	1	1696	-1.03	48.85	1.315	24.65
	2	1720	-0.78	51.31	1.337	24.85
245	1	1688	-1.01	48.52	1.292	24.37
	2	1720	-0.78	51.26	1.337	24,85

Table A-2

DATA SHEET

Combined Tests
(Liquid Density 1000 g/1)

Note: Runs 196 to 217 were made with separate tanks.
Runs 218 to 291 were made with tanks interconnected.

Run No.	Pump No.	Pump Speed rpm	Suction Head psi	Discharge Head psi	Discharge cfs	Brake Horse Power
246	1	1720	-2.43	45.43	1.782	30.45
	2	20	-2.26	46.67	1.782	30.14
247	1	1704	-2.31	44.87	1.738	29.22
	2	20	-2.31	46.48	1.782	30.14
248	1	1696	-2.21	44.63	1.738	28.95
	2	20	-2.31	46.49	1.805	30.14
249	1	1688	-2.16	44.31	1.693	28.67
	2	20	-2.38	46.30	1.805	30.41
250	1	1720	-4.25	39.73	2.228	34.32
	2	1720	-3.88	40.74	2.228	34.30
251	1	1704	-4.10	39.49	2.206	33.59
	2	1720	-3.88	40.69	2.250	34.60
252	1	1696	-3.95	39.12	2.183	32.82
	2	1720	-4.00	40.50	2.273	34.60
253	1	1688	-3.85	38.80	2.161	32.22
	2	1720	-4.03	40.23	2.273	34.46
254	1	1840	0.40	62.84	0.445	17.65
	2	40	0.39	62.49	0.445	17.66
255	1	1824	0.41	61.72	0.445	17.37
	2	40	0.39	62.54	0.445	17.55
256	1	1816	0.41	61.31	0.423	17.37
	2	40	0.40	62.31	0.445	17.55
257	1	1808	0.41	60.66	0.423	17.08
	2	40	0.41	62.36	0.445	17.55
258	1	1840	-0.07	61.68	0.891	24.29
	2	40	-0.09	62.12	0.891	23.21
259	1	1824	-0.08	60.99	0.869	23.44
	2	40	-0.13	62.07	0.891	23.21
260	1	1816	-0.06	60.34	0.847	23.16
	2	40	-0.17	62.22	0.913	23.49
261	1	1808	-0.04	59.69	0.836	22.69
	2	40	-0.17	62.21	0.936	23.58

Table A-2

DATA SHEET

Combined Tests
(Liquid Density 1000 g/1

Note: Runs 196 to 217 were made with separate tanks.
Runs 218 to 291 were made with tanks interconnected.

Run No.	Pump No.	Pump Speed rpm	Suction Head psi	Discharge Head psi	Discharge cfs	Brake Horse Power
262	1	1840	-1.18	58.63	1.337	31.27
	2	1840	-0.88	59.76	1.337	29.60
263	1	1824	-1.03	57.55	1.337	30.58
	2	1840	-0.84	59.39	1.337	29.73
264	1	1816	-1.03	57.00	1.315	29.62
	2	1840	-0.84	59.21	1.359	29.79
265	1	1808	-0.98	56.45	1.292	28.80
	2	1840	-0.84	59.15	1.359	29.79
266	1	1840	-2.50	54.13	1.782	35.60
	2	1840	-2.75	55.07	1.782	35.82
267	1	1824	-2.26	52.79	1.771	35.31
	2	1840	-2.16	54.89	1.782	35.54
268	1	1824	-2.31	52.70	1.738	34.30
	2	1840	-2.14	54.65	1.805	35.54
269	1	1816	-2.26	52.37	1.716	33.15
	2	1840	-2.14	54.70	1.805	36.11
270	1	1816	-2.28	52.65	1.738	34.30
	2	1840	-2.28	54.98	1.805	36.11
271	1	1808	-2.24	52.33	1.738	33.59
	2	1840	-2.21	54.70	1.805	36.11
284	1	1560	0.36	44.96	0.445	12.44
	2	1560	0.28	44.54	0.445	12.18
285	1	1544	0.36	44.13	0.445	12.09
	2	1560	0.28	44.90	0.445	12.07
286	1	1536	0.36	43.89	0.445	11.81
	2	1560	0.28	44.81	0.445	12.07
287	1	1528	0.36	43.43	0.445	11.81
	2	1560	0.28	44.67	0.445	12.07
288	1	1560	-0.17	43.81	0.891	16.66
	2	1560	-0.29	44.16	0.891	16.28
289	1	1544	-0.11	42.92	0.846	16.10
	2	1560	-0.37	43.84	0.936	16.28
290	1	1536	-0.10	42.69	0.825	15.82
	2	1560	-0.39	43.74	0.936	16.28
291	1	1528	-0.08	42.36	0.825	15.31
	2	1560	-0.40	43.70	0.957	16.28

Table A-2